The TREND IN ENGINEERING

at the University of Washington

In this issue:

A LATERAL-FORCE FORMULA BASED ON SEISMOLOGICAL CONCEPTS

AN INVESTIGATON INTO THE USE OF ALGAE IN REMOVING NUTRIENTS FROM DOMESTIC SEWAGE

THE DEVELOPMENT AND EVALUATION OF AN ELECTROMECHANICAL ANALOG COMPUTER

ELASTIC STRAIN-MICROHARDNESS RELATIONSHIP STUDIES

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THE ENGINEERING EXPERIMENT STATION

THE ENGINEERING EXPERIMENT STATION of the University of Washington, which was established in December, 1917, performs a three-fold function:

1) It stimulates, promotes, and coordinates investigations and research in all fields of engineering.
2) It publishes results of significant research achievements.
3) It provides opportunities through Graduate Research Assistantships for engineering students to extend their professional education while pursuing a course of study leading to the M.S. or Ph.D. degree.

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The Station offers a substantial number of Research Assistantships to highly qualified graduate students who are assigned to the academic departments. Results of major investigations are published by the Station in the form of bulletins and reports. Current research findings, as well as listings of sponsored research projects, appear in the quarterly journal, *The Trend in Engineering at the University of Washington.* Reprints of articles by members of the engineering faculty and graduate students published in recognized technical journals are also issued by the Station.

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SCHIZOPHRENIA IN ENGINEERING*

HOMER H. GRANT, *Associate Dean, School of Engineering*
University of Southern California

With the increased use of engineers for fundamental scientific research, the engineering profession is developing a type of schizophrenia, used here in the lay sense of meaning split personality. The advent of Sputnik has further compounded the problem by emphasizing science.

Although the engineering profession appears superficially to be stronger and more important than ever before, it is actually facing a crisis which, left unresolved, may result not only in downgrading engineering but in seriously weakening the future strength of the Nation.

What are some of the reasons for this strange state of affairs and what corrective actions must be taken to avoid such disastrous eventualities?

The traditional role of engineering has been to turn the developments of the scientist in his laboratory into mass products for the use of mankind. Forty years ago this was a relatively simple concept. Rates of change were leisurely. The scientist stayed largely in his laboratory. The engineer restricted himself primarily to design and development, and to the more active pursuits evolving therefrom.

Two distinct types of men characterized science and engineering. The scientist was usually dedicated to exhaustive micro-investigation of extreme minutia in a very narrow field on the forefront of knowledge, frequently a field of his own particular interest and choosing. On the other hand, the engineer had to meet and solve a wide diversity of problems. Usually these problems were in, or related to, his own field but were not of his own choosing. The engineer was expected to produce definite results within a given time period. To do this he called not only on his basic theoretical and experimental training but on broad experience, ingenuity, and a developed intuitive characteristic known loosely as engineering judgment. He practiced largely in fields of macro-investigations where theory needed to be accurate enough only for a desired result within general tolerances of safety, reliability, durability, and cost.

These facts were recognized as late as May, 1959, by the President's Science Advisory Committee, as shown by the following quotations:

> "The word *diversified* should be emphasized, for individuals labeled 'engineers' perform a wide variety of tasks . . ." "He is further distinguished from his colleagues in science in his constant concern to achieve an optimum design to meet the many and frequently conflicting criteria of performance, reliability, efficiency, cost and producibility . . . The associated synthesis, analysis or design of an element or system are unique characteristics of engineering . . ." "The profession of Engineering has thus become one of the most important in modern society."

Gradually the demands for engineers spread from development and design into certain types of operations and management. This was occasioned not by the engineering profession but by the rising technical complexity of services and products, necessitating decision-making at ever higher levels by persons qualified by training to understand the technical implications of such decision. For this reason *Fortune Magazine* could report several years ago that nearly half of the top three men in the 800 major manufacturing companies of the Nation had been trained as engineers. Forty years ago most of these positions were held by accountants, lawyers, financiers, and self-made production men.

With the advent of World War II and later the cold war, the Nation undertook a tremendous expansion of applied research and production requiring super-precision methods, often utilizing relatively new and unknown materials. Owing perhaps to the lack of applied scientists, the spectrum of engineering rapidly expanded into fields of applied research approaching basic research. In turn many scientists were drawn to fill needs in engineering, blurring traditional distinctions in the research and development spectrum. Note, however, that this expansion has not relieved engineering of its responsibilities in other areas.

Engineering education rapidly girded to meet the needs for increasing levels of technical attainment, as well as increasing numbers of engineers, a process continuing at an accelerated pace. Applied scientists appeared on the staffs of engineering colleges, infusing a healthful cross-fertilization. Unfortunately, but naturally, in many instances they brought narrow viewpoints concentrated almost entirely on the basic research portion of the engineering spectrum, with little understanding or interest in engineering as a profession serving the public and conforming to a Code of Ethics.

Engineering licensing laws, now effective in all states, were originally drawn to protect the public from unqualified persons offering to practice as professional engineers. Although still in process of evolution, these laws do not relate primarily to the research part of the engineering spectrum. *Professional registration as a criterion for engineering faculties is declining rapidly as emphasis on basic research increases.* Without attempting here to assess the desirability of this trend, it would seem the professional engineering societies and the engineering teaching profession should give greater consideration to definite objectives and courses of action for engineering.

To drift inadvertently into a situation which will determine the future of engineering by default would seem to be inexcusable. Even now many uninformed persons see no reason why a school of engineering should not be headed by a pure scientist. The sign of professional recognition for the scientist has long been the research doctorate (the Ph.D.), whereas for the engineer it has been primarily the license to practice as a Professional Engineer, consulting status, and salary. Availability of government funds for fairly fundamental applied research, and the need for research men in industry, have led to the development of such research organizations in engineering schools, and to the need for young men with the Ph.D. on engineering faculties. In my opinion this should benefit the profession when the Ph.D. is in engineering, or when an interest in training engineers exists even though the Ph.D. is in science. The benefit is not so tangible when a faculty member is truly interested only in training applied scientists, or is primarily interested only in research *per se.*

Should the distinction between the applied scientist and the engineer again be revived, or does the distinction no longer exist? Should engineering develop its own professional doctorate for those who do not wish to be primarily in highly basic research? Possession of a doctorate is beginning to be important in areas outside of basic research.

(Continued on page 31)

*Presented at the annual meeting of the Pacific Southwest Section, ASEE, Los Angeles State College, December 28, 1959. Dean Grant is an alumnus of the University of Washington, where he holds three degrees, B.S., 1932; M.S., 1933; and E.E., 1946.

THE ACHIEVEMENT OF EXCELLENCE*

DR. C. EASTON ROTHWELL, *President of Mills College*

Before elaborating upon the present American scene, let me direct your attention briefly to those few periods in history in which there was an outpouring of genius. These usually brief interludes of unstinting excellence in both Western and Eastern civilizations have been ones in which there was a harmonious relationship between the individual and his social environment conducive to creative achievement. In western civilization this condition was present in Periclean Greece, in the Florence of the Medicis and the Venice of the great Doges, and in Europe of the Enlightenment. Within these societies the expectation of excellence was widespread. The creative individual deepened and satisfied these expectations among his fellows. At the same time, his own creative powers drew nourishment from the roots of the society of which he was usually a robust part. The great figures of Hellenic Greece, of the Renascence, and of the Enlightenment were neither isolated nor insulated from their compatriots. An intimate and responsive relationship existed between the creative man and the society which expected him to create and shared his pride in creation. Out of it came not any narrow or specialized kind of excellence. There came instead the broad encompassing excellence that the Italians called *virtu,* or which we term "virtuosity."

I fear we shall not find in American society today that same warm creative relationship between the individual pursuing excellence and his fellows. If we are to believe what we read in Vance Packard's *The Status Seekers* and in William White's *The Organization Man,* we derive the picture of a society with a crystallizing social and economic structure, a society that puts a higher premium upon conformity than upon creativity as a means of staying on a well-rutted road to success. Jacques Barzun, in *The House of Intellect,* decries the philistine attributes of our culture that water down intellect and lower us to a mediocrity far below any standard of excellence. Even when we correct the judgments of these critics to the extent that some reviewers insist we must, there remains a large core of truth in what they and others say. Sufficient truth remains to compel us to conclude that in our society there will be little nourishment for those bold young men and women with high expectations of excellence in the less popular, less appreciated sectors of our lives. And it will therefore be a very difficult task, indeed a bootstrap operation, to extend the norm of excellence to the wide spectrum of what we do, what we think, and what we say.

To recognize this situation is not to submit to it. That would be clearly outside the American tradition. At the same time, it is not easy to discover any sure means to overcome the societal drag upon the achievement of excellence. In a measure we can count upon our enemies, or at least those whom we fear, to help the process. The market value of brains rose appreciably after the Russians demonstrated beyond dispute that the Western nations do not have a monopoly on those attuned to contemporary science. The shock reaction as the Sputniks went aloft did not spend itself until it had given a good shaking to the passivity and complacency, if not the hostility, that has surrounded the generation of ideas and the whole educational process in the period since World War II. For this help we can be thankful. The Russians have themselves assisted us to overcome the anti-intellectualism that began to be generated a decade ago by our apprehensions about Soviet communism. I am sure they did not intend this ironic result, but it nevertheless will make easier our own quest for excellence.

As we search within our own society for the most likely instrumentalities with which to reform our values and expectations, we cannot escape the conclusion that the educational system, and particularly our colleges and universities, must assume a large part of the burden. The prospects of their doing so are greater than they were ten years ago or five years ago. This is in part because the colleges and universities are emerging from the restraints and timidities of the early 1950's into positions of bolder leadership. But it is also because the college and university enjoys a more fortunate position than was formerly true in the shaping of the aspirations of our people. The respect for it as an educational institution and as a place where the high mysteries of research are pursued is greater than it was two decades ago. As the carrier and generator of culture, it has regained something of the position it held during the colonial period. This is particularly true when the institution harbors faculty and administrators who have authoritative standing in their fields and know how to communicate well with laymen.

The college and university reaches a number of audiences. I shall confine myself to two—the alumni and the undergraduates. Because the college degree has become a ticket of admittance to the nation's elites of prestige and influence, and for other good reasons, the relations of an institution with its alumni have begun to assume new dimensions. We are indeed moving toward a kind of continuing educational relationship between the college or university and those to whom it awarded diplomas. This relationship has been marked by serious alumni interest in current developments and discoveries in both the liberal arts and the professional fields. There is little left of Joe College as a stereotype. The trend is a wholesome one, and places the college and university in a position to exert a considerable influence toward broader norms of excellence within a very important segment of the nation's adult population.

An even greater opportunity resides in the basic function of the institution of higher learning, the education of its undergraduates and graduates. With the rise in ratio between college graduates and the general population, and with the floodtide now upon us of students seeking a college education, the potential of influence is high indeed. If the eyes of the next college generations can be raised to exacting requirements of performance in the full range of our national activities, within a decade we shall have taken seven-league steps toward excellence.

Some few students can generate their own intellectual energies and find their own way toward values that will inspire high levels of attainment. Most of them will require the catalyst of good teaching. Some rare teachers are capable of getting inside students, of exciting their enthusiasm, and of disciplining them to excellent performance through the medium of the large lecture. Much more frequently these results are produced only by the intimate interaction of mind upon mind and spirit upon spirit. This circumstance presents us with a serious dilemma at the moment when we do not know where we shall find the teachers for the great body of undergraduates that is now beginning to descend upon us.

(Continued on page 26)

* From an address with this title delivered at the Pacific Northwest Conference on Higher Education, Southern Oregon College, Ashland, July 27, 1959.

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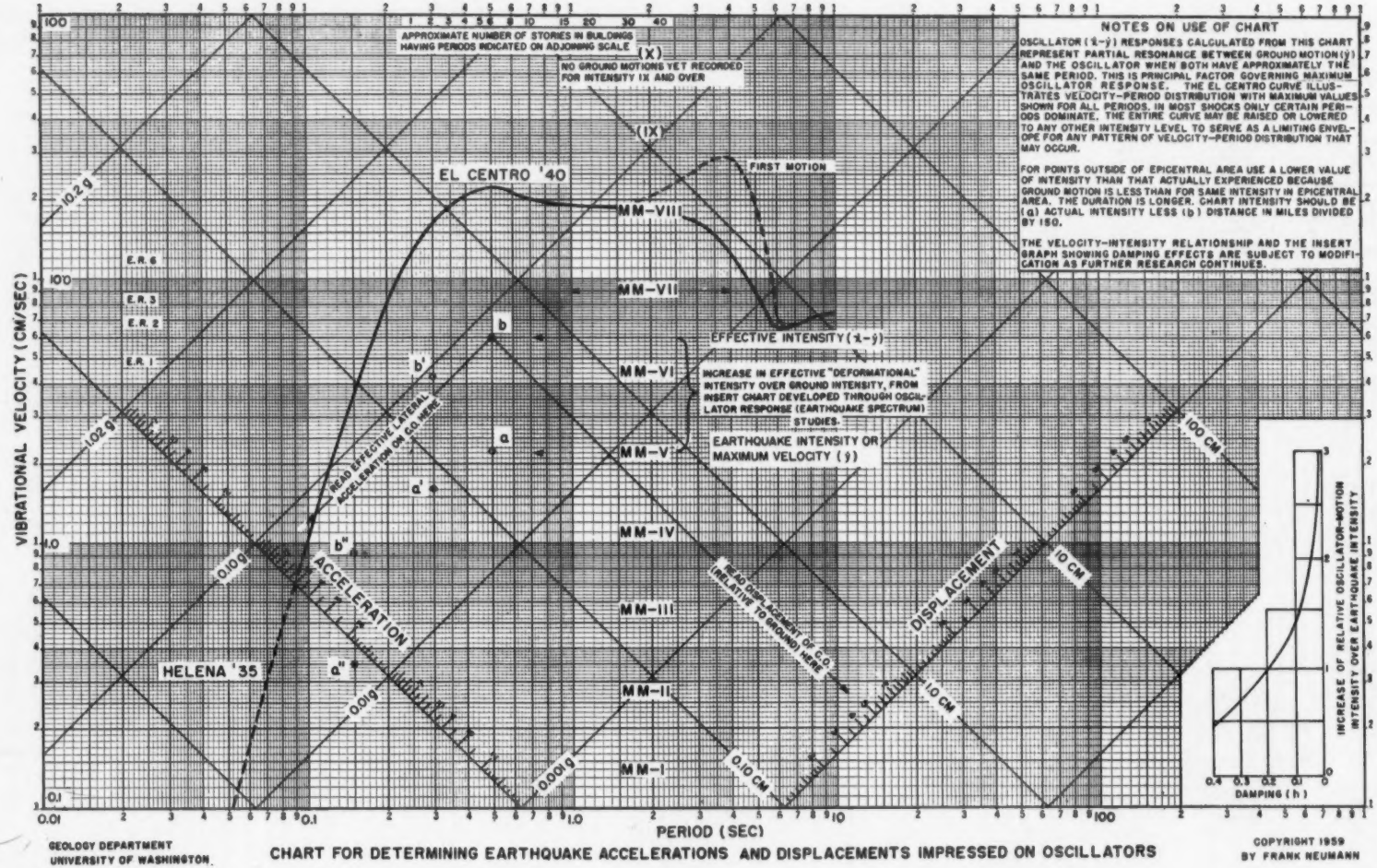
NOTES ON USE OF CHART
OSCILLATOR (ẍ-ÿ) RESPONSES CALCULATED FROM THIS CHART REPRESENT PARTIAL RESONANCE BETWEEN GROUND MOTION (ÿ) AND THE OSCILLATOR WHEN BOTH HAVE APPROXIMATELY THE SAME PERIOD. THIS IS PRINCIPAL FACTOR GOVERNING MAXIMUM OSCILLATOR RESPONSE. THE EL CENTRO CURVE ILLUSTRATES VELOCITY-PERIOD DISTRIBUTION WITH MAXIMUM VALUES SHOWN FOR ALL PERIODS. IN MOST SHOCKS ONLY CERTAIN PERIODS DOMINATE. THE ENTIRE CURVE MAY BE RAISED OR LOWERED TO ANY OTHER INTENSITY LEVEL TO SERVE AS A LIMITING ENVELOPE FOR ANY PATTERN OF VELOCITY-PERIOD DISTRIBUTION THAT MAY OCCUR.
FOR POINTS OUTSIDE OF EPICENTRAL AREA USE A LOWER VALUE OF INTENSITY THAN THAT ACTUALLY EXPERIENCED BECAUSE GROUND MOTION IS LESS THAN FOR SAME INTENSITY IN EPICENTRAL AREA. THE DURATION IS LONGER. CHART INTENSITY SHOULD BE (q) ACTUAL INTENSITY LESS (b) DISTANCE IN MILES DIVIDED BY 150.
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NO GROUND MOTIONS YET RECORDED FOR INTENSITY IX AND OVER
(X)
(IX)
EL CENTRO '40
FIRST MOTION
MM-VIII
MM-VII
MM-VI
MM-V
MM-IV
MM-III
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MM-I
EFFECTIVE INTENSITY (ẍ-ÿ)
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E.R. 6
E.R. 3
E.R. 2
E.R. 1
1.02 g
0.10 g
0.01 g
0.001 g
READ EFFECTIVE LATERAL ACCELERATION ON C.G. HERE
READ DISPLACEMENT OF C.G. RELATIVE TO GROUND HERE
ACCELERATION
DISPLACEMENT
100 CM
10 CM
1.0 CM
0.10 CM
HELENA '35
a
a'
a''
b
b'
b''
VIBRATIONAL VELOCITY (CM/SEC)
PERIOD (SEC)
INCREASE OF RELATIVE OSCILLATOR-MOTION INTENSITY OVER EARTHQUAKE INTENSITY
DAMPING (h)
0.4 0.3 0.2 0.1 0

GEOLOGY DEPARTMENT
UNIVERSITY OF WASHINGTON

CHART FOR DETERMINING EARTHQUAKE ACCELERATIONS AND DISPLACEMENTS IMPRESSED ON OSCILLATORS

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BY FRANK NEUMANN

FIGURE 1

A Lateral-Force Formula Based on Seismological Concepts

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Department of Geology

Frank Neumann

The formula indicated in the title of this paper is intended to serve the same purpose as the lateral-force formulae found in the earthquake provisions of many building codes. Such formulae are now based largely on the 0.1-g. lateral-force concept, but they are modified in cases where this concept obviously does not apply. They represent in general the result of engineering experience and good judgment rather than scientific solutions of the problem. For many years a direct scientific approach was blocked by lack of data on the motion of the ground during damaging earthquakes, but since the early thirties the U.S. Coast and Geodetic Survey, through the expenditure of more than a million dollars, has, to an appreciable degree, filled this gap.[1]

As a result of the initial effort the Survey made, the progress in several directions has been encouraging; but as yet, because of technical difficulties of various kinds, no generally accepted formula based exclusively on seismological concepts has been forthcoming. With the aid of certain relationships and concepts developed over a long period of years, the writer offers in this paper a procedure or provisional formula that he hopes might serve this purpose. Specifically, the formula proposes to estimate the acceleration and displacement impressed on an oscillator (or building) of any period and any amount of damping by an earthquake of any intensity.

Two previous papers published in *Trend* by the writer[2,3] represented important contributions toward a solution, but involved certain restrictions that left something to be desired. It is felt that this void has now been filled. The purpose of the paper is not to repeat the results that have been published but to show how those findings, together with certain new concepts, can be integrated into a rational and relatively simple lateral-force formula. These relationships and concepts will be briefly reviewed and in some cases re-evaluated.

Earthquake Intensity and Related Ground Motion

In Reference 2 published in *Trend* it was argued that intensity (measured by the Modified Mercalli Intensity Scale of 1931) was basically a function of the maximum vibrational velocity of the ground motion. This supersedes the writer's efforts to equate intensity as a function of acceleration and period in the 1954 booklet entitled *Earthquake Intensity and Related Ground Motion.*[4] The present attitude toward this relationship is that in the central area of an earthquake the maximum vibrational velocities corresponding to intensities MM-8, MM-7, MM-6, MM-5, and MM-4 are approximately 18, 9, 4.5, 2.25, and 1.12 cm/sec respectively. This exponential relationship may be continued to MM-1. See Fig. 1 for a graphical exposition of this feature.

A question arises as to how much the duration of a disturbance and the amplification of building motion (over that of the ground) come into the problem of defining a damaging ground motion. Duration does come into the picture as stated in the insert note on the chart in Fig. 1. That note is based on the observation that in the southern California earthquake of 1952 the ground amplitude in, for instance, an MM-5 disturbance 150 miles from the epicenter was only one half the amplitude of an MM-5 disturbance in the epicentral area. Duration is obviously a factor that at least partially governs intensity. The same reasoning evidently applies to short-duration high-frequency blast vibrations also. Because of its short duration a blast vibration appears to require greater ground amplitudes to produce a specified intensity than an earthquake vibration, which usually lasts much longer. Experimental data support this view. In Fig. 1, for instance, the zone above E.R. 6 (to be discussed later) is definitely a potentially damaging zone for quarry blast vibrations, and the amplitudes are definitely higher than those for the lowest category of damaging earthquake vibrations.

With reference to the resonance problem we can argue that, since earthquake vibrations are more likely to produce resonance than the higher-frequency waves found in blast vibrations, the blast vibrations again require greater amplitudes to produce a specified intensity than do earthquake vibrations.

In the case of earthquake waves it seems quite safe to say that the worst types of building disturbances can be attributed to resonance because resonance is possible with virtually every one of the shorter-period waves found in earthquake disturbances. Resonance is responsible for the worst that happens in a community, and it is this which, in turn,

NOMENCLATURE

x = Broadly used to connote the continuing absolute oscillator displacements resulting from a given earthquake motion, y; $\dot{x}$ and $\ddot{x}$ used to indicate corresponding velocity and acceleration.

y = Broadly used to connote the continuing ground displacement in a given earthquake motion; $\dot{y}$ and $\ddot{y}$ used to indicate corresponding velocity and acceleration.

$(x\text{-}y)$ = The continuing differential displacement between moving oscillator and moving ground. The displacement of the ground subtracted from the absolute displacement of the oscillator. Because of frequent repetition of the maximum value of $(x\text{-}y)$, the only value in which interest is centered, this expression is generally used in the text to indicate the maximum, even though it is not so designated.

$(\dot{x}\text{-}\dot{y})$ = Generally used to indicate the maximum differential velocity when an oscillator is subjected to a given earthquake motion. See $(x\text{-}y)$.

$(\ddot{x}\text{-}\ddot{y})$ = Generally used to indicate the maximum differential acceleration when an oscillator is subjected to a given earthquake motion. See $(x\text{-}y)$.

T_g = Period of ground waves in seconds.

T_e = Undamped period of oscillator in seconds.

h = Fraction of critical damping.

ϵ = Damping ratio.

t = Time in seconds.

τ = Time parameter in integration.

governs the intensity assigned to a community. The instrumentally recorded ground motion must be associated with this worst (resonance) effect. Ground-motion intensity is therefore evaluated on its inherent ability to set structures into amplified motion through resonance.

While some aspects of the provisionally adopted intensity-velocity relationship seem fairly clear, and others somewhat vague, the magnitude of the resulting uncertainties is not great enough to justify overall rejection of the figures provisionally being used. They represent the best that can be obtained with the data and resources at the author's disposal. Some modifications may be expected as a result of later and more comprehensive studies. The discussions to follow will show that the advantages accruing from such an intensity-velocity relationship are too important to the earthquake engineer for him to ignore them or to postpone them indefinitely until perfect answers are found to all of the questions that may be raised.

Ground Spectra

The best way to analyze quantitatively the outstanding characteristics of a complex earthquake motion is to construct a so-called ground spectrum for that motion. Such a graph shows the maximum amplitude of each period in the motion. The sometimes laborious techniques involved are explained in References 4 and 5. When, for instance, an earthquake motion is registered only on an accelerograph,

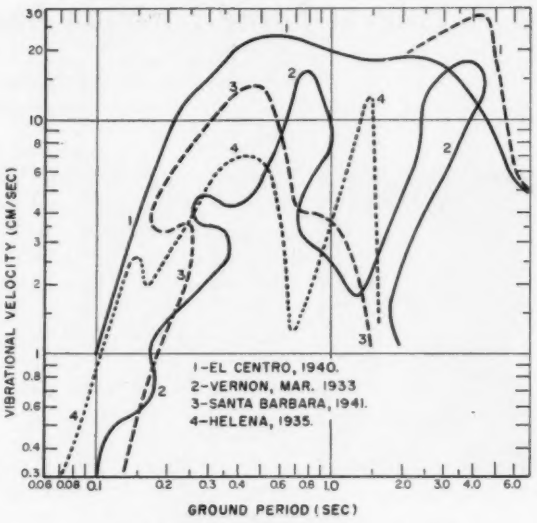


FIG. 2. VELOCITY-PERIOD ENVELOPE FOR FOUR EARTHQUAKES

it is necessary to double integrate the record to obtain the corresponding displacement curves. These curves provide the only source of information on the periods and amplitudes of the longer period waves. There is a great advantage in constructing ground spectra on 4-way logarithmic grids such as that shown in Fig. 1 because any point on the curve (for a given period) can be expressed as an acceleration, velocity, or displacement by referring to the appropriate set of rectangular or diagonal coordinates. The construction of three separate curves to show these properties is unnecessary. The graph shows clearly that maximum vibrational velocity is the only property of a vibration that can be independent of the period of vibration. Because of the exponential character of the intensity-velocity relationship, it also shows that the ratio between any two velocities can be expressed as an arithmetic difference in intensity. Thus a 2-to-1 ratio in velocity always corresponds to a difference of one grade in intensity.

Figure 2 shows four ground-spectrum graphs and reveals how varied in pattern they may be. The spectrum for the El Centro (California) record of 1940 shown in Figs. 1 and 3 is most valuable because it reveals high (maximum) amplitude waves for virtually every period present in a destructive earthquake motion. The curve, which shows the highest amplitudes ever registered on a Coast and Geodetic Survey strong-motion seismograph, serves as an envelope that apparently covers any pattern of spectrum that might be present in an earthquake motion. This point is illustrated in Fig. 2, which shows the El Centro spectrum along with the spectra of three

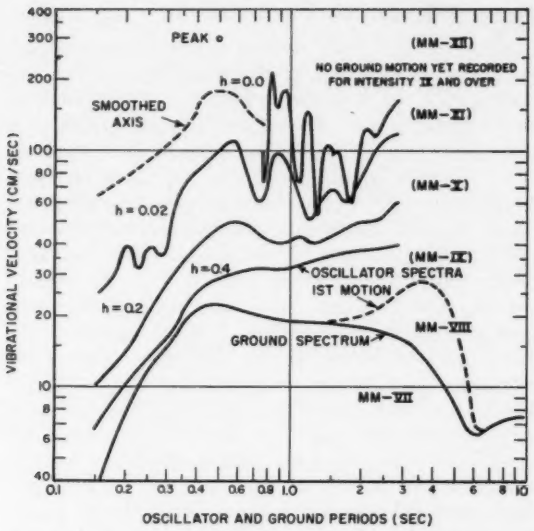
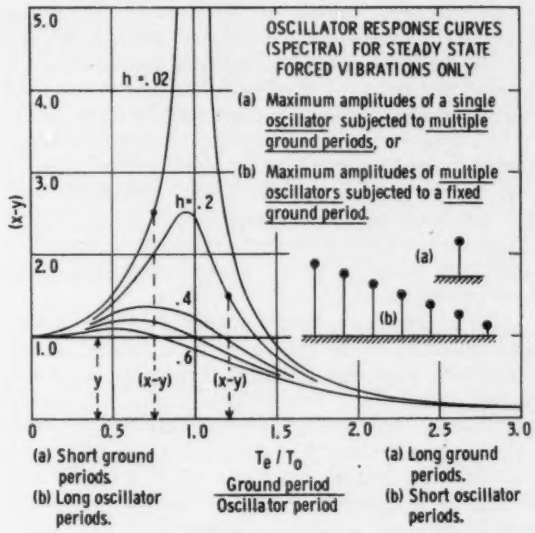


FIG. 3. OSCILLATOR AND GROUND SPECTRA DETERMINED FROM EL CENTRO EARTHQUAKE RECORD (MAY 18, 1940)

other destructive earthquake motions.

There may be some inaccuracy in the long-period portion of this spectrum because the displacement was computed by double integrating the acceleration record, and in this process it was assumed that no permanent displacement of the ground had occurred. A subsequent triangulation resurvey of the area revealed that a permanent shift had occurred. The writer believes, however, that any differences in the period-amplitude readings that might result from reprocessing the original acceleration record would have but little engineering significance. A discussion of the problem follows an article by B. K. Meade entitled "Report on Triangulation for Earthquake Investigation in the Vicinity of El Centro, California," in the 1947 issue of the *Transactions of the American Geophysical Union.*

In any formula designed to include all the expectable periods and amplitudes in an earthquake of any intensity, the writer prefers to use the El Centro spectrum as a representative ground spectrum. Spectra for earthquakes of lower intensity (than the MM-8.3 adopted as the El Centro intensity) can be approximated by simply dropping the El Centro Curve in Fig. 1 to any other intensity level. Emphasis is laid on the fact that a particular earthquake motion may or may not contain wave periods that can set up resonant and perhaps damaging building vibrations, but if such periods are present the proposed formula is designed to take them into account and thus determine the maximum lateral force under the worst possible conditions.

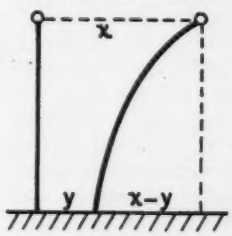


$$(x-y) = 1 \Big/ \sqrt{\left(\frac{Te^2}{To^2} + 1\right)^2 + 4\,\frac{Te^2}{To^2}\,(h^2 - 1)}$$

$$h = \log 10 t \Big/ \sqrt{1.862 + (\log 10 t)^2}$$

FIG. 4. MAGNITUDE CURVES FOR S. H. M.

Steady-State Forced Vibrations



In all forced-vibration studies interest is centered primarily on the relative motion between oscillator and ground, as this measures the deformation of the oscillator at any instant. In the adjoining illustration this is indicated by $(x\text{-}y)$, where x is the absolute motion of the oscillator and y the motion of the ground. Engineering interest is limited chiefly to the maximum deformation $(x\text{-}y)$ experienced during a forced vibration and the acceleration $(\ddot{x}\text{-}\ddot{y})$ and velocity $(\dot{x}\text{-}\dot{y})$ associated with it. The engineer wants to know in particular just how $(x\text{-}y)$ is related to y.

For steady-state forced vibrations of simple harmonic character, the relatively simple solution is found in all textbooks on vibration analysis. The so-called magnification curves in Fig. 4 are typical of the standard mathematical solution. Such curves show the maximum relative motion $(x\text{-}y)$ between the moving oscillator and the moving ground y. The much-desired ratio $(x\text{-}y)/y$ can be read from the graph if the period of the ground motion, T_e; the period T_o; and the damping, h, of the oscillator are known. The curves readily show the responses of a

single damped oscillator to steady-state ground vibrations of constant amplitude but variable period, T_e, or the responses of a series of oscillators to a ground motion, y, of fixed period and amplitude. In Fig. 4 these are designated cases a and b respectively. When the well-known simple harmonic motion equations are used to obtain the maximum velocity $(\dot{x}\text{-}\dot{y})$ and maximum acceleration $(\ddot{x}\text{-}\ddot{y})$ associated with any maximum relative displacement, $(x\text{-}y)$, the period T_e must be used since the oscillator is forced to vibrate in unison with the ground regardless of its own period, T_o.

The structural engineer's interest, however, is limited primarily to the maximum deformations associated with resonance, or near resonance, and low values of damping. This implies that he is generally not interested in the small deformations associated with ground periods that are much greater or much less than the oscillator period. For this special case it may be assumed that, since T_e and T_o are about equal, one may compute the accelerations and velocities associated with the maximum resonant displacement by simply substituting T_o for T_e. This makes a calculation based on this assumption independent of the ground period. The point is given emphasis because, when T_o is substituted for T_e, the expressions for maximum $(x\text{-}y)$, $(\dot{x}\text{-}\dot{y})$, and $(\ddot{x}\text{-}\ddot{y})$ then take on the same forms (to be shown later) as are used in expressing similar maximum oscillator responses to complex nonperiodic earthquake vibrations.

The writer believes that virtually all earthquake vibrations can be treated basically as steady-state vibrations for the following reason: the basic element of an earthquake vibration is a relatively smooth wave train (Reference 4, pp. 19-20). If an oscillator were to be subjected to such a wave motion, its response in terms of $(x\text{-}y)/y$, could be estimated quite readily from standard magnification curves such as those illustrated in Fig. 4. Among seismologists, application of this principle is standard practice when computing the ground motion, y, from "smooth" types of ordinary seismograph records that provide the $(x\text{-}y)$ data. The difficulty in strong-motion records is that two, three, or more wave trains may be impressing several types of wave trains on the seismograph pendulum simultaneously. If the $(x\text{-}y)$ response of a particular oscillator could be computed for each wave train present and if all of the individual responses were then combined, the resulting motion would approximate that obtained when the $(x\text{-}y)$ values are computed directly from strong-motion seismograph records (see Fig. 5). This last procedure will be discussed further in the next section. The wave-train concept is important: it will later be shown to play an important part in the development of the proposed lateral-force formula.

Nonperiodic Forced Vibrations

This section concerns the theoretical $(x\text{-}y)$ response of an oscillator of given period, T_o, and damping, h, to a given earthquake motion such as that registered on a strong-motion seismograph. One may disregard the wave-train concept just advanced as a feasible approach to the oscillator-response problem because a very direct solution was proposed by M. A. Biot[6] in the early 1930's. His mathematical solution for obtaining maximum $(x\text{-}y)$ from a complex earthquake ground motion is now widely known; but for some years application of his equation to practical problems was delayed because of the labor involved in solving the integral portion of the equation. The writer independently suggested the use of a torsion pendulum for computing oscillator responses of this kind.[7] In 1943 Biot reported the results of comprehensive torsion-pendulum studies made at the California Institute of Technology.[8] Subsequently Alford, Housner, and Martel found the electrical analog computer better adapted to this purpose and, after adding a damping factor to Biot's equation,[9] proceeded to calculate a large number of so-called "earthquake spectra."[10] These curves show the maximum $(x\text{-}y)$ responses of groups of damped oscillators to many strong earthquake motions registered on Coast and Geodetic Survey strong-motion seismographs. The following form of equation was used in these final analyses:

$$(x-y)=\frac{T}{2\pi}\int_o^t \ddot{y}(\tau)e^{\frac{2\pi h}{T}}\sin(t-\tau)dt=\frac{T}{2\pi}S,$$

$$(\dot{x}-\dot{y})=S,$$

and

$$(\ddot{x}-\ddot{y})=\frac{2\pi}{T}S,$$

where t is the time in seconds, τ is the time parameter in integration, and h is the damping. The oscillator spectra for the El Centro record of May 18, 1940, together with the corresponding ground spectrum determined by the writer, are shown in Fig. 3.

The problem confronting engineers is to utilize these spectra to the best possible advantage. As was previously stated, though maximum $(x\text{-}y)$ values are important, they must be associated with the corresponding maximum values of y if a solution similar to that for steady-state vibrations is to be developed. This solution appears to be feasible.

Oscillator Spectra vs Ground Spectra

As previously stated, so-called "earthquake spectra," or oscillator spectra, have been made available

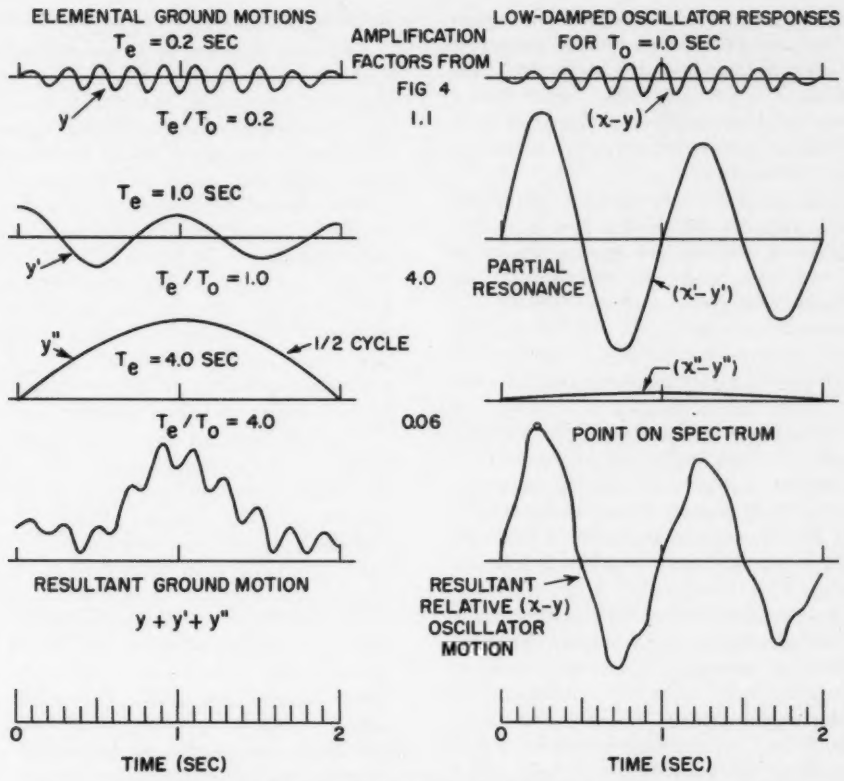


FIG. 5. ILLUSTRATIONS OF THE WAVE-TRAIN CONCEPT OF EARTHQUAKE GROUND MOTION AND OF THE LOW-DAMPED OSCILLATOR RESPONSE

through the Earthquake Research Laboratory in the Engineering Department at the California Institute of Technology. They are basically "max *(x-y)*" curves. There are also a limited number of ground-spectrum curves, most of them developed by the writer. The El Centro ground spectra were first published in 1940.[11] Others were never published in Coast and Geodetic Survey reports, but some appear in monographs by the writer.[4,12] These spectra are basically "max *y*" curves. The oscillator spectra show the maximum responses of oscillators of different period and damping; the ground spectra show the maximum responses of ground oscillations of different period. The paramount question is whether a relationship can be established between *(x-y)* and *y* similar to that found in steady-state vibrations as illustrated in Fig. 4.

In References 3 and 13 the writer expressed the belief that fixed *(x-y)/y* ratios could be established for various degrees of oscillator damping only within a narrow period range that was associated with the maximum amplitudes (velocities) of both the oscillator and the ground spectra. This restricted the information on oscillator responses to those oscillator periods associated with the over-all maximum oscillator responses—not to any maximum oscillator response. The author now believes that such *(x-y)/y* ratios are basically constant over the entire range of oscillator periods. The following arguments support this concept:

When a ground period is read out of a record, the writer visualizes that wave as part of a wave train, as previously pointed out. Because a wave train closely approximates a steady-state vibration, the *(x-y)* response for that particular wave can be estimated from the standard magnification curves illustrated in Fig. 4. If one takes any period and amplitude associated with the El Centro ground spectrum and determines the maximum *(x-y)* responses of several low-damped oscillators of different period, he will find that the oscillator showing the greatest *(x-y)* response is always the one having the same period as the ground wave. In other words, the *(x-y)* amplification factor for the case of resonance is so much greater than for other cases that a reso-

nant response between ground and pendulum periods becomes the dominant factor in determining over-all oscillator-spectrum amplitudes. Figure 5 illustrates this point. Since it is obvious from Fig. 4 that a fixed oscillator damping implies a fixed $(x\text{-}y)/y$ ratio for any case of resonance, the basic constancy of this ratio is established.

It should be obvious, however, that while resonance plays a dominant role in outlining the over-all amplitude and pattern of a spectrum, ground waves of other periods will also exert an influence on the oscillator and may be expected at times to badly distort the picture of a constant $(x\text{-}y)/y$ ratio. As seen in Fig. 3, this is exactly what happens. Another factor that may contribute to this distortion deserves some thought. Since the integration of seismograph records in obtaining spectral readings involves arbitrary choices of axes (corresponding to constants of integration), one can only conjecture as to the extent to which errors of judgment in this procedure might also contribute to the complex character of the computed oscillator responses and to variations in the $(x\text{-}y)/y$ ratio.

As should be obvious from the complexity of oscillator spectra, the best the structural engineer can ever expect in predicting earthquake forces on structures is a rather rough estimate, especially if the damping is low. Analyses of the type discussed here show the degree of certainty or uncertainty involved in all estimates of lateral force based on spectral curves. This, of course, includes the lateral-force formula proposed in this paper.

By drawing smoothed axes through the oscillator spectra in Fig. 3, one can deduce values of the $(\dot{x}\text{-}\dot{y})/(\dot{y})$ ratios for the different degrees of oscillator damping shown. These ratios are shown in graphical form on the insert diagram in Fig. 1. It is of interest to compare the resonant amplifications obtained for various degrees of damping in two situations, (a) in the case of a sustained forced vibration and (b) in that of partial resonance resulting from a complex earthquake motion. For the four cases of $h = 0.0$, 0.02, 0.2, and 0.4 the amplifications for a sustained vibration are infinity, 25, 2.5, and 1.25 respectively. In the case of the El Centro, 1940, analysis they are 8 ± 5, 6, 2, and 1.5 respectively. It seems safe to assume that the El Centro case represents an extreme in low amplification because of the complexity of the ground motion. It seems safe to presume also that, as other records are similarly analyzed, the amplification factors will increase with increasing epicentral distance since the ground vibrations will then tend to become smoother. The factors will move in the direction of those found in steady-state vibrations. Fortunately, as the epicentral distance increases the ground amplitudes generally decrease.

Oscillator Accelerations and Displacements

The final problem is to ascertain the acceleration and displacement impressed on an oscillator. This calls for determining the maximum values of $(\ddot{x}\text{-}\ddot{y})$ and $(x\text{-}y)$ when an oscillator of given period and damping is subjected to an earthquake motion of given intensity. Since the maximum oscillator motion is caused by a ground wave having the same period as the oscillator, since the maximum expectable amplitude, $\dot{y}$, of that wave can be obtained from the El Centro ground spectrum (for any intensity), and since the ratio $(\dot{x}\text{-}\dot{y})/\dot{y}$ is known for different degrees of oscillator damping, determining $(\dot{x}\text{-}\dot{y})$ and the corresponding values of $(\ddot{x}\text{-}\ddot{y})$ and $(x\text{-}y)$ is a simple calculation. This is expeditiously accomplished on the grid shown in Fig. 1.

The notations on Fig. 1 illustrate how the grid can be used for this purpose. They show the procedure for determining $(\dot{x}\text{-}\dot{y})$ *and* $(x\text{-}y)$ values for oscillators having periods of 0.5, 0.3, and 0.15 sec. The damping, h, is assumed to be 0.1, and the oscillators are supposedly subjected to an MM-5 earthquake. On the ordinates corresponding to these periods the intersections with the El Centro curve show the values of $\dot{y}$ for an MM-8.3 earthquake. In each case these values of $\dot{y}$ must be lowered 3.3 intensit grades to obtain values of $\dot{y}$ for MM-5. These are marked a, a', and a''. Since $h = 0.1$, the insert chart shows that all values of $\dot{y}$ must be increased by 1.4 intensity grades to obtain $(\dot{x}\text{-}\dot{y})$. These points are shown at b, b′, and b″. The required values of $(\dot{x}\text{-}\ddot{y})$ and $(x\text{-}y)$ are obtained by referring to the diagonal acceleration and displacement coordinates as shown at b. This acceleration serves the same purpose as the acceleration expressions in building-code formulae. The displacement reading expresses the maximum displacement (relative to the ground) of the center of oscillation of a building having the same period and damping as the oscillator. Building code formulae are restricted to acceleration only.

The notations E.R. 1, 2, etc., on the chart indicate the ground velocities associated with safe and with potentially damaging blast vibrations. In some states the 1 and 2 levels are considered safe. F. J. Crandell[14] considers the zone between 3 and 6 a caution zone beyond which the vibrations are potentially damaging.

Showing Building-Code Formulae Graphically

Figure 6 illustrates how building-code formulae covering lateral-force provisions can be shown graphically on the 4-way logarithmic grid. It provides a ready means of comparing different formulae and evaluating their probable effectiveness. To aid in this comparison, an effort has been made at the top

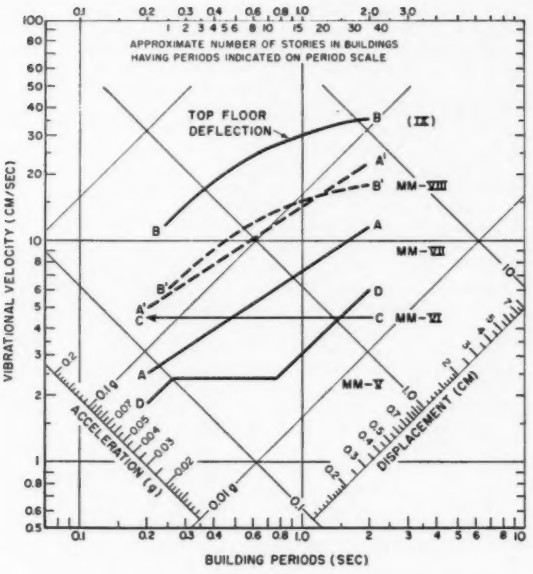


FIG. 6. BUILDING-CODE FORMULAE SHOWN ON FOUR-WAY LOG CHART

of the grid to relate the period of a building to its height in stories. This is, of course, subject to wide variation; the figures on the chart are intended to serve only as a very rough guide. They are based on data published in Reference 1.

The line marked DD defines the accelerations stipulated in the so-called "Joint Committee" (San Francisco) code.[15a] Line CC represents the lateral force provision in the Uniform Building Code of 1958 and some years prior to that.[15b] The line AA represents a proposed formula based on the equation

$$C = \frac{0.05}{\sqrt[3]{T}},$$

in which C is the acceleration factor and T the building period.[15c] The latter formula is expected to replace the two others soon.

The remaining lines on Fig. 6 illustrate an approach suggested by the writer, the basic assumption being that the deflection of the top of a structure should never exceed by more than .001 the height of the structure; otherwise, damage may be expected, particularly in gypsum plaster.* If one assumes certain heights for multistoried buildings, this ratio can be shown on the chart since the diagonal displacement grid can be used as a measure of $(x\text{-}y)$ deformations. The line BB shows this deformation pattern based on the writer's choice of building heights. Since one is concerned primarily with the motion of the center of oscillation of a structure, not the roof, the BB values are reduced one half, to line B′B′, to indicate very approximately the deformation $(x\text{-}y)$ of the center of oscillation of the building. This brings the curve down to roughly double the values indicated by the new code formula mentioned in the preceding paragraph. One need only apply a safety factor of two to the code formula to obtain virtual agreement with this purely seismological approach. Clearly the new empirically developed code formula is in closer agreement with this seismological concept than the formulae in earlier codes.

* A. L. Miller, "Plaster Cracking as a Measure of Building Motion," *The Trend in Engineering*, Vol. 8, No. 1, Jan., 1956, pp. 11-13.

Conclusions

To the practicing engineer who desires to make use of a formula such as this, two recent developments should be of special interest. One concerns the values of damping, h, to use for different kinds of buildings. Such values will be found in a technical report entitled "Frictional Effects in Composite Structures Subjected to Earthquake Vibrations" by Lydik S. Jacobsen, Department of Mechanical Engineering, Stanford University, Stanford, California, March, 1959.

The other development concerns microtremor research being undertaken by Dr. K. Kanai of the Earthquake Research Institute of Tokyo University. Using a highly sensitive but portable seismograph, Dr. Kanai is observing, at many different sites, the periods that are normally present at those sites. By this means, he hopes to predict the dominant periods to be expected in potentially damaging earthquakes. Nonexistent periods will likewise be revealed. When the evidence is published, it may show that, if the period of a new structure is correctly chosen, the chances of going into a damaging resonant vibration are virtually zero. Earthquake engineers should look forward to Dr. Kanai's report with great interest. In some cases, at least, the need for a formula based primarily on resonance may be eliminated.

Some aspects of the formula proposed in this article are encouraging; others may arouse skepticism. On the optimistic side may be listed the ultimate simplicity in its application to specific problems. If one is willing to accept the idea that the formula furnishes the best estimate possible with the information available, he need not be concerned with the many technicalities involved in its development. He may find room for optimism in the apparent agreement between this purely seismological solution and one of the most recent engineering solutions, as revealed in the new building-code formula discussed in the preceding section.

On the pessimistic side the areas of uncertainty have been discussed and evaluated in the text. Though an expanded and more efficient observational program will obviously be required to eliminate them entirely, there is no reason why the suggested technique cannot be employed with the data now available. Criticism in the past has centered largely on the claim that no specific procedure has even been proposed for utilizing the seismological data in the design of structures. This paper proposes a very definite procedure based entirely on these data and on purely seismological concepts.

Aside from the need for more comprehensive studies of the kind outlined in this and the reference papers, the writer believes that this type of formula may be as far as the seismologist can go in contributing toward the building-response phase of the earthquake-engineering problem. The matter of overtone vibrations, since it is concerned largely with the distribution of mass, is an engineering problem. The seismologist's field of interest is restricted primarily to the measurement and analysis of vibrations and to simple oscillator responses to those vibrations as exemplified in the principles of seismometry.

ACKNOWLEDGMENTS

The writer is indebted to Professors A. L. Miller of the Civil Engineering Department and F. B. Farquharson, Director of the Engineering Experiment Station, for encouraging this research and assisting in a better understanding of the engineering phases of the lateral-force problem. Professor H. A. Coombs, Executive Officer of the Geology Department, made it possible to pursue the research by placing emphasis temporarily on the engineering phase of the Department's seismological program.

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    (b) "Uniform Building Code," 1958 Edition, Internat. Conf. of Building Officials, Los Angeles.
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PROGRESS ON NUCLEAR REACTOR BUILDING

The basic construction of a new UW Nuclear Reactor Building was completed on June 20 with the pouring of a concrete roof. As described in the January *Trend*, the two-story concrete and glass structure, which will house a critical nuclear reactor, is part of a College of Engineering program to assist the study of graduate students in nuclear engineering. An outstanding feature of the building is an observation deck for viewing the reactor from the outside. Assembly of the component parts of the reactor will begin in August; and the construction is to be completed in October.

The reactor is a cooperative undertaking of chemical, civil, mechanical, and metallurgical engineering. It is a basic facility in a comprehensive nuclear-engineering program leading to a M.S. degree in engineering.

Professor A. L. Babb, supervisor of the reactor, plans a critical operation of the facility on December 2 to commemorate the 18th birthday of the first critical operation of a nuclear reactor.

An Investigation into the Use of Algae in Removing Nutrients from Domestic Sewage

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R. H. Bogan

Excessive enrichment of receiving waters by nutrient-rich wastes appears to be emerging as a major water-pollution problem in many areas. An urgent part of this problem is the discharge of sewage into natural lakes or streams, which may receive such quantities of phosphorus as to suffer a serious impairment of quality and a marked restriction of subsequent use. Several articles in *Trend* during the last several years have discussed this subject, especially as it relates to the effects of Seattle waste flows into Lake Washington and Puget Sound.

No satisfactory method has been developed to forestall undesirable enrichment. Limnological investigations indicate that, where domestic sewage serves as the primary source of eutrophication, treatment for the removal of phosphorus would provide a practical and effective means of control.[1] This treatment, unlike the use of algaecides, would be permanent and, as in the case of diversion, would not suffer the possible disadvantage of degrading other drainage basins. In spite of these obvious advantages, a suitable method of treatment has yet to be worked out.

Phosphorus may be removed from sewage by biological or by chemical means, either approach being aimed at converting soluble inorganic phosphorus into recoverable insoluble matter. Of the two, chemical coagulation has received the greatest attention. Though several promising chemical-treatment methods have been proposed, these are costly; and little has yet been done with biological treatment.

The purpose of this article is to explore the employment of algae as a means of removing these nutrients from domestic sewage. Although this concept has received only a limited amount of attention, wherever possible the author draws upon pertinent data reported by others. A larger part of what follows is based upon research carried out at the University of Washington in the past three years. During this investigation the concept of employing algae to remove phosphorus was studied in the laboratory and, on a pilot-plant basis, in the field. The results of this work are encouraging.

THEORETICAL CONCEPTS

Phosphorus Metabolism

The concept of removing nutrients by biological means can hardly be considered as new or unique. In any actively growing biological system nutrient materials are constantly being extracted from the environment through conversion to cell tissue, the rate and degree of removal depending upon the biological system employed and upon the environmental conditions provided.

Other things being equal, the rate of removal is a function of the rate of cell-tissue synthesis. Growth rate varies considerably with the type of organism, as shown in Table I. The mixed microbial culture provided by the activated-sludge process would appear to be the most effective biological system in terms of removal rate. Theoretical daily phosphate removal rates are shown in Fig. 1 for several concentrations of cell tissue having growth rates comparable to those commonly reported for algae. This figure shows a theoretical relationship among cell-tissue concentration, growth rate, and metabolic conversion of phosphorus by algae.

Cell-tissue composition together with the mineral content of a sewage will determine the amount of phosphorus that can be extracted. Examination of the data presented in Table II indicates that assimilation of 1 mg/L of phosphorus would be accompanied by the metabolism of 25 to 50 mg/L or more of carbon and 2 to 12 mg/L of nitrogen. It is interesting to note the similarity in the C,N, and P content of algae and of activated sludge.

Nutritional Limitations

Ordinary domestic sewage, being deficient in carbon and nitrogen relative to the amount of phosphorus normally present, does not provide a balanced diet for activated sludge. Organic carbon is usually limiting. But algae do not suffer from the same dietary restrictions, adequate amounts of carbon normally being available in the form of alkalinity. The inorganic nitrogen content of domestic sewage, however,

TABLE I

COMPARISON OF COMMONLY REPORTED GROWTH RATES

Type of Organism	k*(day^{-1})
Algae	0.20 to 2.0
Protozoa	1.0 to 4.0
Bacteria	2.0 to 60

* Based on $N_t = N_o e^{kt}$

TABLE II

COMPOSITION OF ACTIVATED SLUDGE AND COMMON FRESH-WATER ALGAE

Biological System	C % dry wt.	N % dry wt.	P % dry wt.
Activated Sludge* **	41 - 53	8 - 12	0.7 - 2.2
Algae†	49 - 60	1.4 - 11	0.9 - 2.0

* S. R. Hoover and N. Porges, "Assimilation of Dairy Wastes by Activated Sludge—II," *Sew. and Ind. Wastes, 24,* 306 (1952).

** E. N. Helmers *et al.* "Nutritional Requirements in the Biological Stabilization of Industrial Wastes," *Sew. and Ind. Wastes, 24,* 496 (1952).

† R. W. Krauss, Chapter 8, *Algal Culture from Laboratory to Pilot Plant,* Carnegie Inst. of Washington, Publication 600, Washington, D.C., 1953.

TABLE III

EFFECT OF TEMPERATURE AND CULTURE MEDIA ON GROWTH RATE, *STIGLEOCLONIUM STAGNATILE

Temperature °C	Synthetic Sewage Employing NO_3–N	Synthetic Sewage Employing NH_3–N	Secondary STP Effluent
	k days^{-1}**	k days^{-1}**	k days^{-1}**
10	0.165	0.140	0.170
15	0.188	0.179	0.215
20	0.252	0.131	0.131†

* The pH varied from 8.3—9.5; illumination was at 400 fc.

** k computed from $N_t = N_o e^{kt}$

† *Scenedesmus* appeared and began to predominate after approximately 15 days.

TABLE IV

PHOSPHORUS AND NITROGEN CONTENT OF *STIGLEOCLONIUM STAGNATILE

Constituent	Synthetic Sewage NO_3–N	Synthetic Sewage NH_3–N	Secondary STP Effluent	½ STP Eff. ½ NO_3–N Syn Sew.
N	5.71	6.59	6.52	6.00
P	2.16	1.81	1.89	2.07
N/P	2.64	3.63	3.44	2.89

* Harvest from various culture media. Content expressed as % of dry cell weight. Values reported from an average of several determinations.

TABLE V

PHOTOSYNTHETIC pH CHANGES IN LAGOON CELLS

AUTUMN, 1958

Time (Days) →	1	2	3	5	7	10	12	15	Remarks
Lagoon Cell 1	7.7	7.6	8.4	8.7	8.5	9.4	9.5	10.1	Intermittent aeration plus artificial illumination (400 fc.). p.m.
2	8.0	7.7	8.4	8.8	8.9	9.2	9.2	9.6	Int. aeration: no artificial illum.
3	8.1	8.0	8.5	9.1	9.3	9.7	9.7	10.4	No. aeration; no artificial illum.
4	8.1	7.5	8.2	10.4	...	...	...	...	Int. aeration. Air off after day 6.
Time of Sampling	1:30 p.m.	11:00 a.m.	11:00 a.m.	11:30 a.m.	10:30 a.m.	3:00 p.m.	11:30 a.m.	12:00 noon	
Weather	Cldy.	Cldy.	Pt. Cldy.	Rain	Sunny	Pt. Cldy.	Sunny	Sunny	All lagoon cells filled with secondary treatment-plant effluent and seeded with equal volume of algal culture.
Temperature °C	...	...	14	...	12	11	10	11	
Susp. Solids mg/L	...	28	33	36	36	62	62	70	

still may be in short supply. There is evidence that atmospheric nitrogen fixation might be made to serve as a significant source of nitrogen.[1] Agricultural grade NH_3-N could also be employed as a relatively inexpensive nitrogen source.

Viewed thus in terms of nutritional requirements, algae appear to offer the most effective biological system for extracting phosphorus from domestic sewage.

Observed Phosphorus Reductions

If the biosynthesis reaction is based on a carbon-to-phosphorus ratio of 100 to 1[2] and a settled raw-sewage BOD lying in the range of 100 to 200 mg/L, phosphorus reductions during the course of biological sewage treatment would, on the average, be limited to about 1 to 2 mg/L. In an investigation of the performance of sewage plants in Minnesota, Owen[3] found phosphorus removals ranged from an average of 2% for plants employing screening and sedimentation only to an average of 24% for plants employing biological treatment; this is equivalent to approximately 1 to 2 mg/L of P. An analysis of the effluents from a number of biological sewage-treatment plants in the Seattle area disclosed a reduction ranging from 15 to 40%, which is equivalent to 0.80 to 2.0 mg/L of P.

A number of excellent research reports have appeared in the literature dealing with algal behavior in oxidation ponds and raw-sewage lagoons.[4,5,6,7] Attention has been centered mainly upon the use of photosynthetic oxygen production. Very little data have been reported regarding nutrient reductions realized in such processes; however, available information indicates phosphorus reductions ranging from 10 to 90% or better. Performance appears to be erratic and unpredictable. Considerable difficulty has been experienced in harvesting the algal cell tissue; this, coupled with slow growth rate, would account for some of the wide fluctuations noted in the mineral composition of lagoon effluents.

Methods of Using Algae

The most direct method of using algae as a means of recovering nutrients would appear to be cultivation in an oxidation pond equipped with a separation operation for harvesting the algae. With such an arrangement sewage would be continually mixed with actively growing algae and the nutrients gradually converted to cell tissue; and cell tissue would be recovered for reuse or wasted according to need. Experience indicates that the principal problem would be the harvesting.

Several unit operations have been investigated as a means of harvesting algal cell tissue.[4] Those most frequently referred to in the literature are screening, settling, centrifuging, and chemical coagulation. All

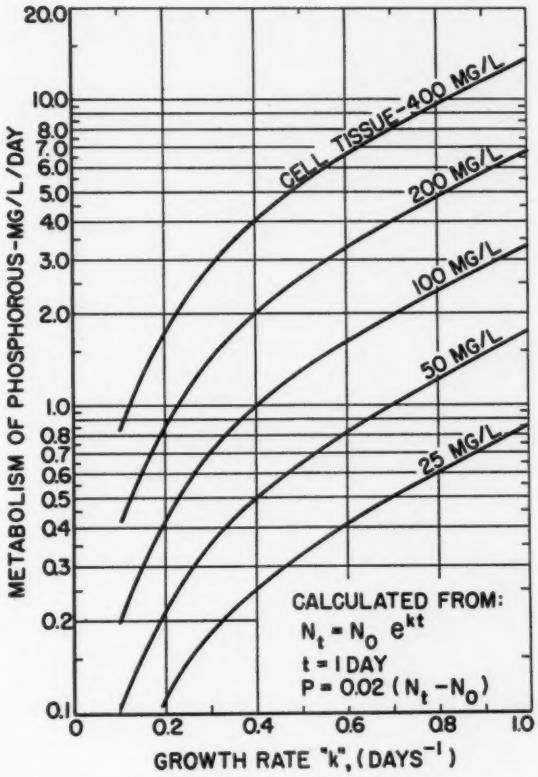

FIG. 1. THEORETICAL PHOSPHATE REMOVAL RATES
Light intensity will determine cell-tissue concentration; temp, diet, and species regulate k (mean k = 0.30 days).

have been found wanting in some aspect, generally in terms of efficiency and often in terms of cost. For performance and economy, a process using some type of screening device appears to be the most promising.

The separation performance of a screen obviously would be related to the nature of the algal culture. If some readily recovered alga could be established, then, through the simple mechanism of recovery and reuse, it could be made to predominate. Other things being equal, the process would naturally tend to contain the most readily utilized population. The ideal organism would appear to be a large, rapidly growing, filamentous alga.

There is little evidence that filamentous species of the type desired normally grow in oxidation ponds or sewage lagoons; but this does not preclude the possibility of their being cultivated under such conditions. Failure of filamentous species to constitute a significant part of the population of most oxidation ponds may be due to the fact that they are relatively slow growers and simply tend to be overgrown by rapidly growing algae, such as *Chlorella* and *Scenedesmus*.

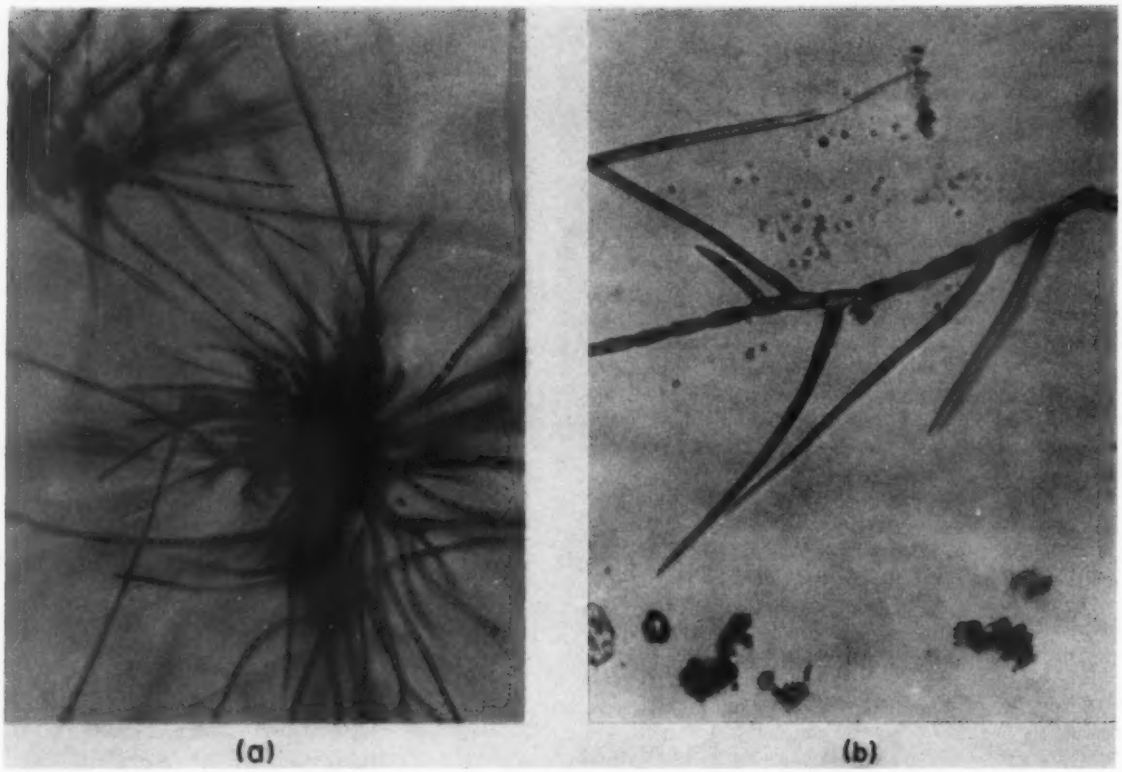

FIG. 2. PHOTOMICROGRAPHS of *STIGLEOCLONIUM STAGNATILE*
Floc-like colonies (a) that developed in aerated culture (about 220X) and (b) an individual organism (about 520X)

THE EXPERIMENTAL WORK

In the investigation at the University of Washington, the use of algae in removing phosphorus from sewage was studied in the laboratory and the field. Though several fundamental concepts related to using algae for this purpose came under investigation, space does not permit a description of all the major aspects of this research. The following account briefly describes the more significant findings concerning available algae, mechanism of phosphorus removal, physical-chemical behavior of orthophosphate, photosynthetic pH adjustment, and cell-tissue recovery.

Available Algae

Several common fresh-water algae were grown in the laboratory on mixtures of lake water and raw and treated sewages. However, except for *Chlorella* and *Scenedesmus* most species gradually died out after a brief period of active growth. Then a large filamentous alga, subsequently identified as *Stigleoclonium stagnatile*, was recovered from the rock of a biological filter in the area and successfully cultured. When grown under aeration, this alga developed into settleable floc particles resembling activated sludge. Photomicrographs of *Stigleoclonium stagnatile* are shown in Fig. 2. Its growth characteristics and nitrogen and phosphorus content are shown in Tables III and IV.

Mechanism of $PO_4^{\equiv}$ Removal

It was expected that phosphorus removal would follow a pattern predicted by cell-tissue composition and growth rate (see Fig. 1). Contrary to expectations, orthophosphate residuals in batch-fed cultures were found to decrease at a rate considerably in excess of that predicted by biological uptake. Response to repeated heavy phosphate doses was most interesting: in general some 80 to 90% of the phosphate added was removed from solution within two hours, as shown in Fig. 3. Obviously more than metabolic uptake was involved. Examination of culture characteristics disclosed that phosphorus removal was related to pH. It thus appeared that coagulation and adsorption may have played a significant role. Interestingly, the photosynthetic response was not visibly impaired by repeated use of cell tissue.

At moderately high pH levels, generally in the

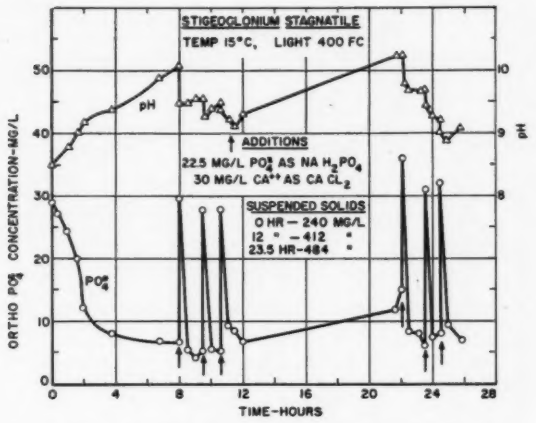

FIG. 3. RESPONSE OF BATCH-FED ALGAL CULTURES TO REPEATED DOSES OF $PO_4^{\equiv}$

Aerated *Stigleoclonium* showed a remarkable capacity for coagulating and adsorbing orthophosphate.

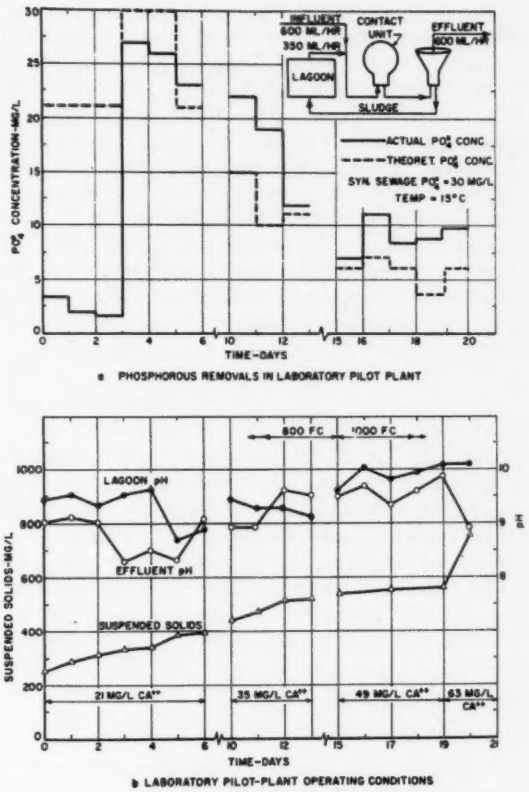

FIG. 4. LABORATORY PILOT-PLANT PERFORMANCE

...nge of 9.5 to 10.0, large amounts of phosphorus were extracted rapidly from solution without the use of auxiliary chemicals. At lower pH levels, the rate of phosphorus removal should, of course, be determined largely by algal growth rate. This hypothesis was subsequently tested in the laboratory and in the field. Typical laboratory pilot-plant performance is shown in Fig 4. At pH levels of 9.5 and above, field cultures exhibited phosphate reductions comparable to those observed in laboratory batch and pilot-plant studies.

$PO_4^{\equiv}$ Behavior

Under suitable conditions, orthophosphate may combine with a number of substances commonly present in sewage to form relatively insoluble complexes. Calcium ion concentration and pH were found to be the principal controlling factors in determining $PO_4^{\equiv}$ solubility; their relationship is shown in Fig. 5. Ammonia, iron, and magnesium in the amounts generally encountered in domestic sewage were not found to exercise any discernable effect on phosphate solubility.

Photosynthetic pH Adjustment

A study was made of the role of algae in adjusting pH. Such factors as temperature, cell-tissue concentration, composition of culture media, and alkalinity naturally would be expected to influence the rate of photosynthetic pH adjustment. Interestingly, light intensity was found to be the principal influence. Photosynthetic pH response under carefully controlled laboratory conditions and under field conditions is shown in Fig. 6 and Table V. Where light was not limiting, the pH response followed a pattern such as that shown in Fig. 6. Under field conditions light intensity became limiting and the rate of pH change was consequently markedly reduced.

Judged solely on the basis of rate of pH adjustment, minimum light-intensity requirements appear to lie in the vicinity of 100 to 200 fc. Where such light intensities are possible, the pH of raw and treated sewages may be photosynthetically increased to 9.0 and above within 4 to 12 hours.

Cell-Tissue Recovery

When it was found that *Stigleoclonium stagnatile* could be effectively recovered by sedimentation, the concept of screening as a recovery device was abandoned. Repeated use of a *Stigleoclonium* culture during successive batch-culture feedings or cell-tissue recycling in pilot-plant operation resulted in a marked improvement in settling characteristics. Apparently the adsorption of insoluble calcium phosphate salts by the algae caused coagulation of cell tissue, thereby increasing its rate of subsidence.

During pilot-plant studies, the *Stigleoclonium* culture became contaminated with *Chlorella* and *Scenedesmus*. At temperatures above 20°C, *Chlorella* and *Scenedesmus* tended to predominate; *Stigleoclonium* was simply overgrown. This tendency gave rise to some serious misgivings at first until it was observed that culture settling characteristics varied little with species, owing to the coagulation effect of the insoluble phosphate salts produced at high pH levels. This observation is most interesting, for it implies that the algae in most oxidation ponds may be effectively recovered by sedimentation if they are first permitted to increase pH levels above approximately 9.5 before recovery is attempted.

DISCUSSION

Algae are capable of removing phosphorus from solution both by metabolic uptake and by chemical coagulation and adsorption. Adsorption and coagulation appear to play the major role where rapid removal of large concentrations of phosphorus is involved. The relative significance of biological uptake depends, of course, on algal growth rate, environmental conditions, and upon time available for growth. In any of these cases, the photosynthetic activity of the algae governs the rate of removal.

High-Rate Process

Laboratory pilot-plant studies employing an illuminated contact unit followed by sedimentation have demonstrated that a high-rate continuous-flow process is functionally feasible when light is not limiting. Orthophosphate concentrations can be reduced to less than 1 mg/L within 6 to 12 hours. This is equivalent to a 90 to 95% reduction in the phosphorus content of most sewages. Residual phosphate concentrations of about 3 to 5 mg/L were realized with contact times as brief as 2 to 4 hours.

While a high-rate algal treatment process appears to be functionally sound, economic considerations restrict the use of algae to the more leisurely conditions prevailing in oxidation ponds and sewage lagoons. Process costs are related to the cost of pH adjustment, which in turn is a function of light requirements and holdup time. Where artificial illumination is employed, power requirements—and hence cost—can be computed from a knowledge of lamp performance and of the light-attenuation rate in the algal culture. The cost of pH adjustment employing artifical and natural illumination is compared in Fig. 7, together with the cost of pH adjustment by lime alone. The lime requirements were computed from titration curves of a number of treated sewages in the Seattle area. Economy considerations appear to preclude the use of artificial illumination.

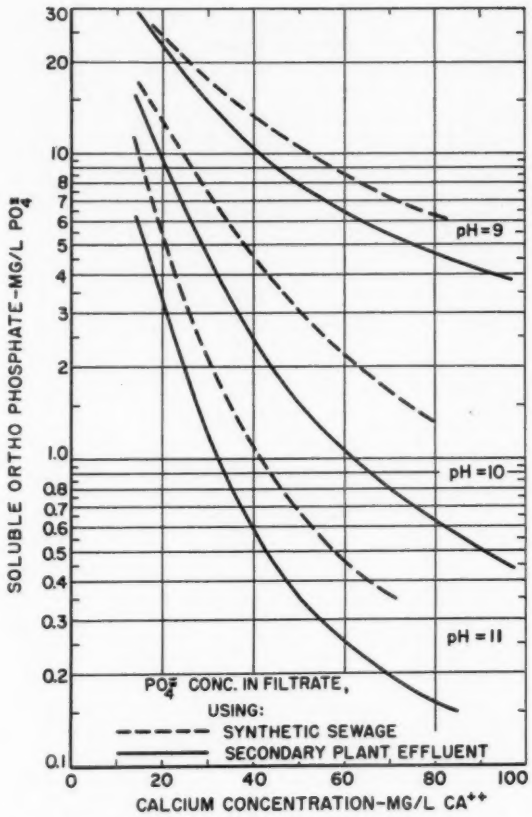

FIG. 5. INFLUENCE OF pH AND CALCIUM CONCENTRATION ON SOLUBILITY OF $PO_4^{\equiv}$

Calcium ion concentration and pH were adjusted by using $CaCl_2$, $Ca(OH)_2$, and NaOH; samples of synthetic sewage and filtered sewage based on filtered supernatant.

Lighting Limitations

Owing to a high rate of light attenuation, the maintenance of adequate illumination in large-scale cultures is difficult. Theoretical considerations based on the Beer-Lambert Law indicate that it ordinarily would not be possible to maintain light intensities above 100 fc by natural or artificial means in depths much greater than 1 ft. Current practice is to construct oxidation ponds and lagoons with depths ranging from 3 to 5 ft.

As a practical matter, where thorough mixing occurs, the effect of employing depths greater than that involved in photosynthesis is roughly equivalent to illuminating the entire culture at a proportionately lesser intensity. The net photosynthetic response is thus reduced; and a longer contact time must be provided to achieve a given degree of pH adjustment. For example, 12 hours of contact time at 100

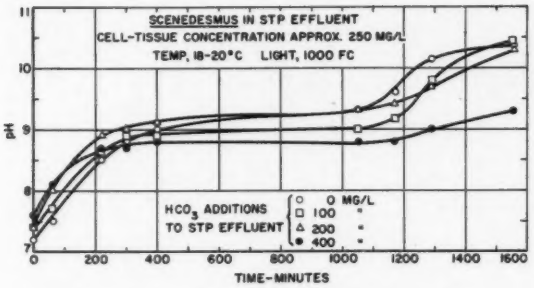

FIG. 6. INFLUENCE OF HCO_3^- CONCENTRATION ON PHOTOSYNTHETIC pH SHIFT

At 200 fc and above, *Stigleoclonium*, *Scenedesmus*, and *Chlorella* caused rapid increases in the pH of sewages; normal alkilinity had little effect on pH.

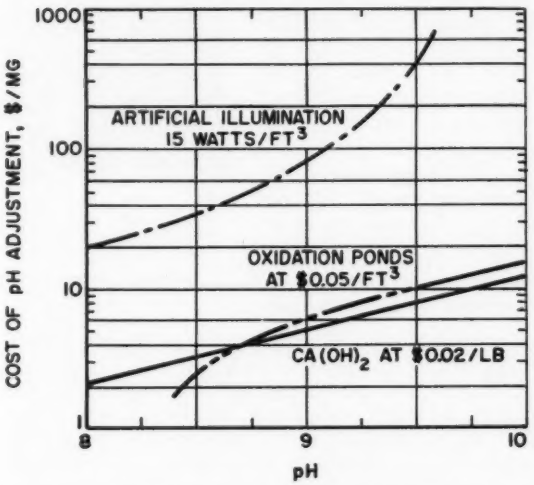

FIG. 7. COSTS OF THREE METHODS OF ADJUSTING pH

The costs and requirements were based as follows: electrical energy, at $.01/kwhr; power required, on h-v fluorescent elements and the culture-extinction coef 2 X 10^{-5} cm^2/mg; oxidation ponds, on a const. cost of $0.50 ft^3, a useful life of 20 yr, and a liquid depth of 4 ft; and lime requirements, on titration curves for sewages in the Seattle area.

fc were found to be approximately equivalent to 10 to 12 days of lagoon-retention time under field conditions prevailing in the Seattle area during the fall of the year.

Detention-Time Requirements

Theoretically an oxidation pond should be capable of very high efficiencies of phosphorus removal. In order to realize this potential, active photosynthesis and/or high pH conditions must prevail for some time prior to discharge. Where biological fixation is the principal mode of phosphorus removal, efficiency will be a function of detention time, growth rate, and cell-tissue concentration.

During field pilot-plant studies, algal cell-tissue concentrations in lagoon units having a depth of 3 to 4 ft varied from 25 to 50 mg/L. The average growth rate was equivalent to a k of 0.30 day^{-1}. Thus, in order to extract biologically 5 mg/L of P (equivalent to 80 to 90% reduction for most sewages), lagoon retention times on the order of 14 to 28 days apparently would be required. Theoretical retention-time requirements for any other set of circumstances can be calculated from the data presented in Fig. 1. These considerations suggest that pond volume in excess of that employed in most oxidation ponds may be necessary where a high degree of phosphorus removal is a treatment objective.

Summary of Results

Through a high-rate process developed in the laboratory, soluble phosphate reductions equivalent to 90% or better were achieved with contact times as brief as 6 to 12 hours. The process subsequently was studied in the field, along with the behavior of conventional sewage lagoons.

The experimental results presented in this article are briefly summarized below:

1. In the presence of adequate amounts of light, rapid photosynthetic extraction of phosphate can be realized. Minimum light requirements appear to be in the vicinity of 100 to 200 fc.
2. Under normal field conditions adequate light intensities seldom prevail in algal cultures at depths much in excess of 1 ft. The use of deeper ponds, as is common practice today, serves in effect to decrease net illumination roughly in proportion to the ratio of light and dark volumes. Photosynthetic reaction times are markedly increased.
3. Adsorption and coagulation appear to play the major role where rapid removal of large amounts of phosphate is involved. Metabolic conversion is the principal removal mechanism under the more leisurely conditions prevailing in oxidation ponds and sewage lagoons. In the latter case efficiency of phosphate removal is proportional to detention time, other things being equal.
4. Three algae, *Chlorella*, *Scenedesmus*, and *Stigleoclonium*, were grown in raw and treated sewages. Repeated reuse of these algae generally improved subsidence properties without noticeably impairing photosynthetic response. Settleability appeared to be influenced by the formation of insoluble phosphates at elevated pH. The evidence indicates that the photosynthetic pH shift may be employed as a means of enhancing the recovery of algae by sedimentation.

(Continued on page 24)

The Development and Evaluation of An Electromechanical Analog Computer*

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Since the invention of the calculus by Newton and Leibnitz nearly three hundred years ago, man has been concerned with solving differential equations. Lord Kelvin, in 1876, suggested the possibility of machine solution; but it was not until 1925 that a successful mechanical integrating computer[2] was developed, through the efforts of Dr. Vannevar Bush at M.I.T. This was followed in 1930 by a larger general-purpose machine.[3] The resulting interest produced a number of mechanical differential analyzers in Europe and America, culminating in an elaborate machine,[4] completed at M.I.T. in 1942, which was used extensively for wartime projects.

Since then, mechanical analog equipment has been gradually superseded by electronic analog computers made possible by the tremendous postwar improvements in electronic computing devices. Electronic computers are capable of much faster operation, are simpler to connect for a variety of problems, and are much less cumbersome and costly. However, for specialized applications the mechanical analog computer retains certain definite advantages, the primary one being its unique ability to integrate with respect to any variable, independent or dependent, although the digital differential analyzer can do this by finite increments. The mechanical analog computer will continue to hold this advantage until electronic integrators are built that do not depend on time-constant components. A second advantage is that the mechanical computer is usually more accurate and reliable than the electronic type.

The value of the mechanical differential analyzer for both research and instruction prompted the development of the small mechanical computer shown in Fig 1. It has been used to demonstrate the solutions to certain first- and second-order linear differential equations. Further applications are planned, particularly in the solution of nonlinear equations. The remainder of this paper summarizes fundamentals of mechanical analog computation, describes components and the methods used for assembling them into the operational computer just mentioned, and gives examples of its performance.

P. L. Balise

Principles of the Mechanical Analog Computer[5,6,7,8,9]

A mechanical analog computer is a physical analogy of the mathematical equations describing a system. Each variable (and each derivative of the variable) is represented by a shaft whose angular displacement is the value of the variable at any instant of time. The shafts are interconnected through various mechanical components that perform the required mathematical operations.

Addition and subtraction are accomplished by a mechanical differential. The output shaft is geared 1 : 2, since otherwise its rotation would be half the sum of the input shaft rotations. A positive sign is arbitrarily assigned to a direction of rotation of each shaft. To perform subtraction, the shaft corresponding to the negative term is rotated in its negative direction.

Multiplication by a constant is performed by the wheel-and-disc variable-speed drive shown in Fig. 2. The wheel displacement equals the disc displacement times the constant r_1/r_2, or

$$\theta_2 = \frac{r_1}{r_2}\theta_1 . \qquad (1)$$

Integration is obtained by mounting the wheel shown in Fig. 2 on a carriage that may be traversed

* Condensed and arranged from Mr. Laine's thesis[1] for the degree of MS in Mechanical Engineering under the supervision of Professor P. L. Balise.

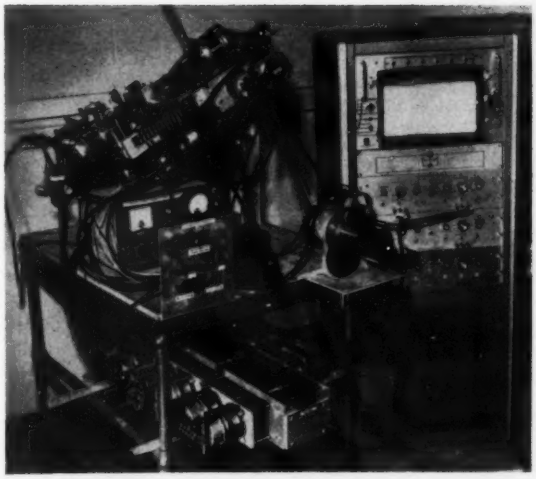

FIG. 1. THE ELECTROMECHANICAL ANALOG COMPUTER

by turning a threaded shaft, thus varying r_1 continuously in proportion to the rotation of the threaded shaft. Equation (1) is then written in differential form,

$$\theta_2 = \frac{1}{r_2} \int r_1 \, d\theta_1 . \tag{2}$$

The integration can be performed with respect to any variable that can be represented by an angular displacement. If the integration is performed with respect to time, the integrator disc is rotated at a constant angular velocity. All the power required to drive computer components is derived from the disc drive system. Differentiation is avoided in any analog computer, if possible, because it is a noise-amplifying process. If differentiation is necessary, it is achieved by an approximate procedure that can be made to approach a true derivative as closely as the noise level will permit. The method is based on the implicit equation

$$Z = K(x - \int Z d\theta_1). \tag{3}$$

Transposing and differentiating yields

$$\int Z d\theta_1 = x - \frac{Z}{K} \tag{4}$$

so that

$$Z = \frac{dx}{d\theta_1} - \frac{1}{K} \frac{dZ}{d\theta_1} . \tag{5}$$

The differentiation mechanization is shown in Fig. 3. The output, Z, represents the derivative of the

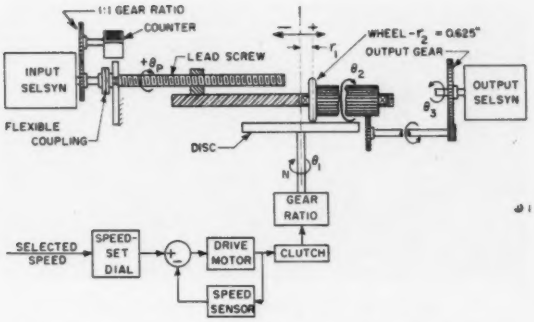

FIG. 2. INTEGRATOR ASSEMBLY AND DRIVE SYSTEM

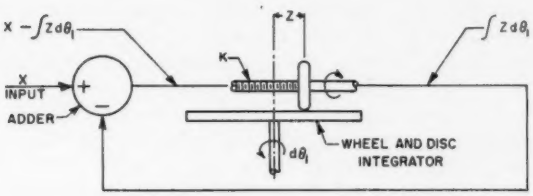

FIG. 3 MECHANICAL DIFFERENTIATOR

input, x, minus an error term that is inversely proportional to K. In practice, K is made as large as possible consistent with the requirements of system stability. If the disc is rotated at a constant angular velocity so that θ_1 corresponds to time, then a time derivative results.

Combinations of the adder, multiplier, and integrator can be used to generate many types of functions, including polynomials, reciprocals, ratios, exponentials, and trigonometric functions. The latter are obtained by connecting the components to correspond to differential equations whose solutions are the desired functions.

Various methods have been used for interconnecting the components. The most common are mechanical means—such as shaft couplings, belts, or chains—and electrical methods utilizing servomechanisms or Selsyns. Each system has certain advantages, depending on the particular application of the computer. A general-purpose mechanical analog computer used to solve many different types of equations requires a convenient, rapid method such as that provided by electrical systems.

Development of the Computer

The basic units for building the computer were those in a World War II Navy-surplus dead-reckoning computer containing four wheel-and-disc variable-speed drives. Two of the drives were suitable for integrators and two for constant-coefficient multipliers, to be used in an arrangement limiting the

FIG. 4. ARRANGEMENTS OF INTEGRATORS

computer to solutions of second-order differential equations. A bank of adders, integrator-traversing mechanisms with limit switches, a component-interconnection system, multiplier-coefficient indicators, and other instrumentation illustrated in Figs. 4, 5, and 6 were designed and constructed. Thorough study of various methods of interconnecting components revealed that a Selsyn system would fulfill all of the requirements. Eleven pairs of a-c Selsyns were installed, one on the input and another on the output shaft of each component. These Selsyns develop sufficient torque to permit direct drives without the need of intermediate servo amplifiers. The integrator wheel-traversing mechanism consists of accurate low-torque lead-screw assemblies and counters for facilitating insertion of initial conditions. Axial displacements of the wheels are sensed with linear potentiometers and recorded on a Brush recorder. Limit switches monitor the wheel travel of the integrator by tripping the computer power relay in event of an impending over-travel condition. A shaft-position readout assembly, containing a linear potentiometer, allows recording of any shaft displacement by connection to the appropriate Selsyn. A bank of three differential adders utilizes a 1 : 2 output-gear ratio for exact addition and subtraction of variables.

The transfer functions of the components were determined, and all the components were calibrated. Figure 7 shows the component characteristics required for solution with this particular computer.

Operation and Demonstration

Mechanization of a differential equation for a general type of analog computer is discussed in detail in Reference 5. However, idiosyncracies of this particular computer must be considered in order to generate the correct solution to an equation.

The method of attack is presented for mechanization of a linear second-order homogeneous differential equation with constant coefficients:

$$M\ddot{X}+C\dot{X}+KX=O. \tag{6}$$

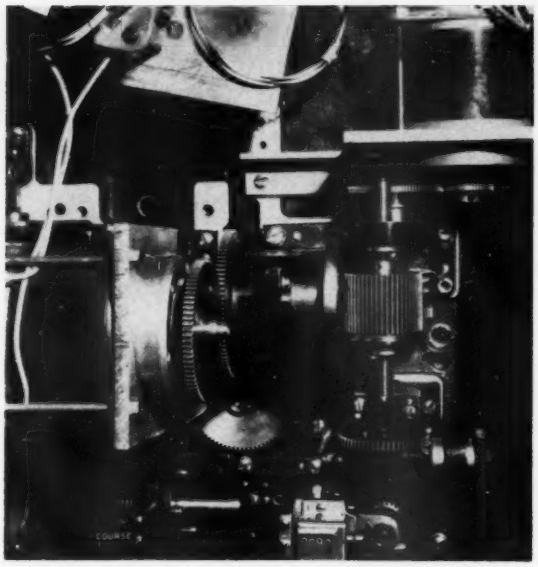

FIG. 5. A MECHANICAL MULTIPLIER

The highest derivative is isolated:

$$\ddot{X}=\frac{C}{M}\dot{X}-\frac{K}{M}X. \tag{7}$$

The quantity $\ddot{X}$ is inserted into the first of two integrators in series, yielding $\dot{X}$ and $-X$ as shown in Fig. 8. The cables interconnecting the various Selsyns are cross connected wherever a negative cable-transfer function appears. The quantities $\dot{X}$ and X are inserted into their respective coefficient multipliers and added. The negative of the output of the adder is fed back and connected to the input to the first integrator, compelling agreement between the right and left sides of Eq. (7).

Initial conditions are inserted by displacing the associated shaft prior to starting the computer. The problem solution is then generated by rotating the integrator discs at a constant speed, determined by the desired ratio of computer time to real time. A change in disc speed may be desired for more effective study of the solution, or may be required because of limitations, such as inertia effects, in the components and the readout equipment.

The solutions of the differential equations

$$\dot{X}=AX \tag{8}$$

and

$$\ddot{X}=-C\dot{X}-X \tag{9}$$

are shown in Fig. 9, which also shows the theoretical

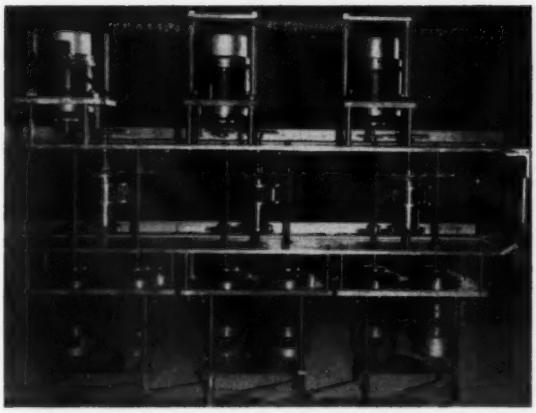

FIG. 6. A BANK OF ADDERS

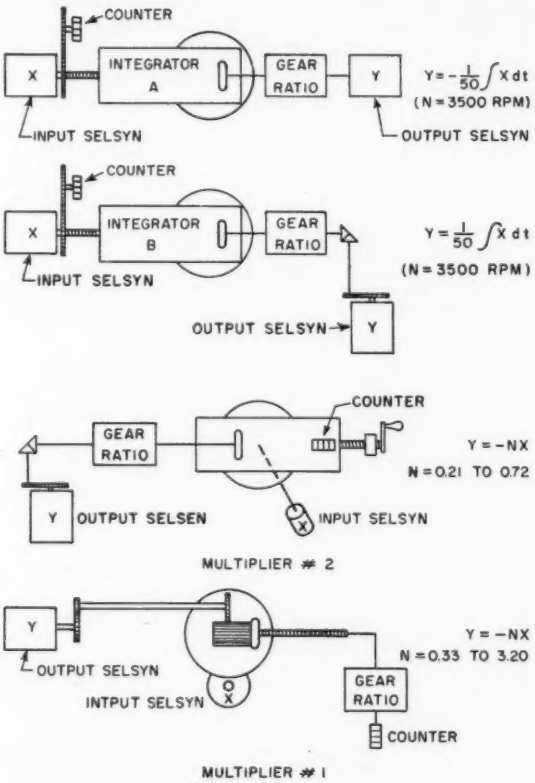

FIG. 7. COMPONENT CHARACTERISTICS

and generated exponential curves of the solutions to Eq. (8). The solutions of Eq. (9), subjected to a step input of displacement, are shown in Fig. 10. The actual undamped natural frequency agrees within 1% of that calculated.

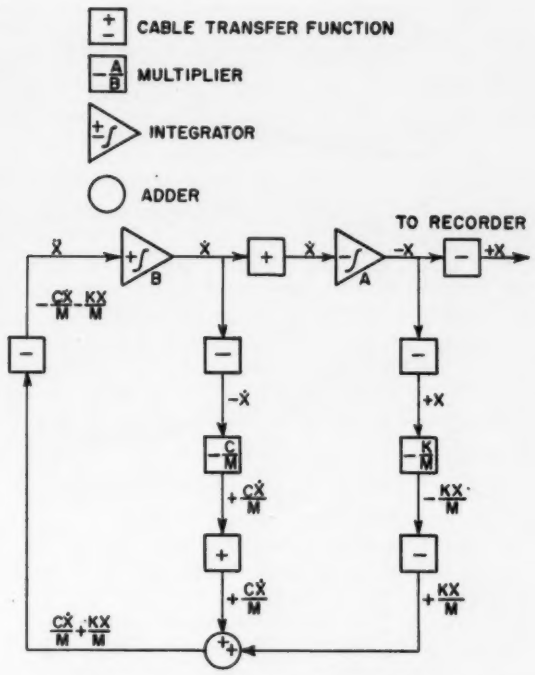

FIG. 8. MECHANIZATION OF $M\ddot{X} + C\dot{X} + KX = 0$

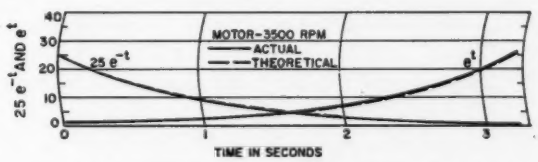

FIG. 9. COMPUTER GENERATION OF 25 e^{-t} AND e^{t}

Evaluation of the computer reveals that it is capable of solving linear homogeneous first- and second-order differential equations with coefficients limited by the multiplier ranges. Solutions can be generated with less than 2% error.

A development program is continuing to expand the capabilities of the computer. Linear and nonlinear input devices, additional integrators, and wideband multipliers are being considered. These components would allow steady-state and transient solutions to high-order linear and nonlinear equations.

The educational potential of the computer is virtually unlimited. The authors especially hope that its demonstration and use will inspire mechanical-engineering students at the University of Washington to appreciate the value of analog computers as engineering tools.

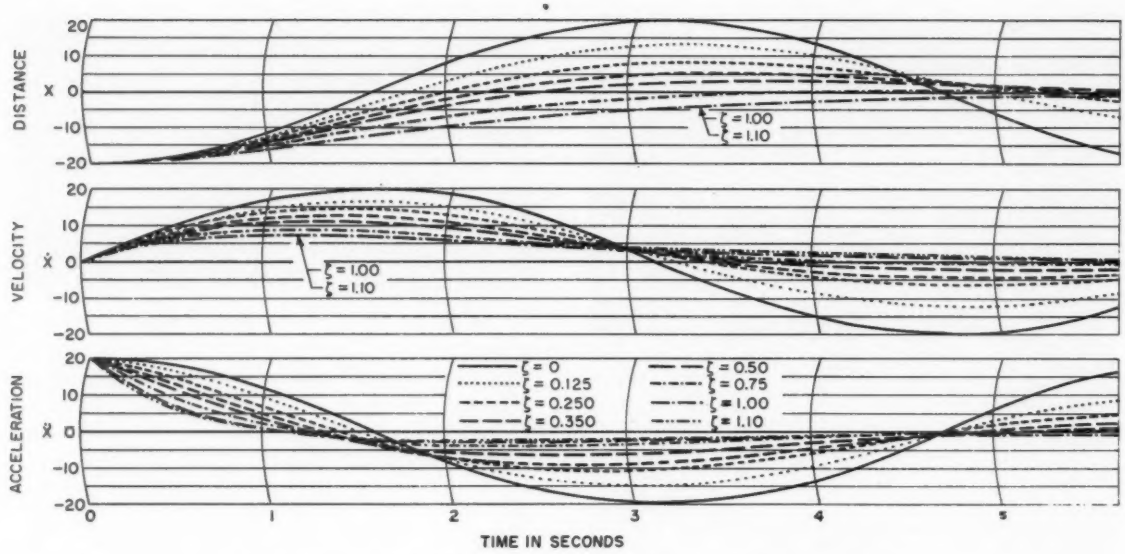

FIG. 10. GENERATION OF $\ddot{X} + C\dot{X} - X = 0$ FOR VARIOUS DAMPING RATIOS

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AN INVESTIGATION INTO THE USE OF ALGAE

(Continued from page 19)

ACKNOWLEDGMENTS

A number of the writer's former students participated in the work described in this article. Messrs. Orris E. Albertson and James C. Pluntze were responsible for process development and study. Initial phases of this work, including the laboratory pilot-plant studies, were supported by the University of Washington Engineering Experiment Station. The City of Seattle provided funds for construction of the field-scale pilot plant.

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Elastic Strain-Microhardness Relationship Studies

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The work hardening that occurs during the plastic deformation of metals is a commonly encountered yet incompletely understood phenomenon. A much less well known or understood effect is the apparent strain softening found when metals are deformed in tension within the elastic range. The purpose of this presentation is to report on initial studies aimed at obtaining more quantitative data on the hardness decreases found by elastically straining a series of specimens of a single aluminum alloy. Previous investigations[1,2,3,4,5] on different alloys have reported a generalized decrease in hardness with tensional elastic strain, but the authors believe that the value of these findings is limited, either because of the small strains used or the accuracy of the measurements.

The material selected for investigation was 2024 aluminum alloy, an important commercial metal. The as-received stock was sheets of different thickness, but processed in all cases to the -T3 condition (solution heat treated and then cold worked). Standard tensile specimens with gauge sections ½-in. wide were machined from the sheet. The gauge section of each tensile specimen was first chemically polished, then measured to obtain the average cross-sectional dimensions. A strain gage was attached to one surface of the specimen, and a tension load was applied in a standard 60,000-lb Reihle testing machine. The strain was induced in the specimen to a predetermined value within the elastic range, and a restraining clamp was locked on while the specimen was retained in tension.

The clamp and specimen were then removed as a unit to the microhardness tester. Hardness measurements were taken perpendicularly to the specimen axis and entirely across the gauge section. Usually twelve readings were taken, and the average was used as the plotted hardness value. The deviation in hardness values was normally about ±5% of the average value.

The following sections describe a number of features of the experimental technique that are worthy of more detailed consideration.

Microhardness Measurements

The choice of microhardness rather than the more conventional Rockwell hardness values used by other authors[1,2] seemed prudent because of the small cross section of the specimens and because of the greater accuracy the former method provided. Considerable checking was done before the final value of a 1000-g load on the tester was selected as the best compromise among the various factors to be considered—e.g., indentation size, uniformity, and sharpness—for the surface preparation used.

A careful data log was kept of the position of the hardness determination on the surface of a specimen; thus a review of the hardness readings across the section of a specimen made it possible to be sure of uniaxial loading of the tensile specimen. No such loading difficulty was experienced in any of the specimens.

Preparation of Surface

The problem of providing a smooth surface for microhardness measurements proved to be one of the most trying tests in the overall investigation. The particular alloy chosen for this work is especially unsuitable for electropolishing, the procedure commonly used for the preparation of highly uniform surfaces on many metals. As a consequence, all attempts of this kind that seemed logical failed. Mechanical polishing eliminated the problem of local electrolytic cells, but it proved too difficult a procedure to obtain the degree of polish necessary for microhardness testing. The best results were obtained by a rapid chemical-polishing method. A solution, made up primarily of phosphoric acid, was used. Immersion times were between 3 and 5 minutes.

Specimen Clamp

During the removal of the tensile load, some relaxation of the specimen occurred. No serious problem arose from this effect, as the actual strain in the clamped specimen could be measured with the strain gauge after removal from the tensile machine. The

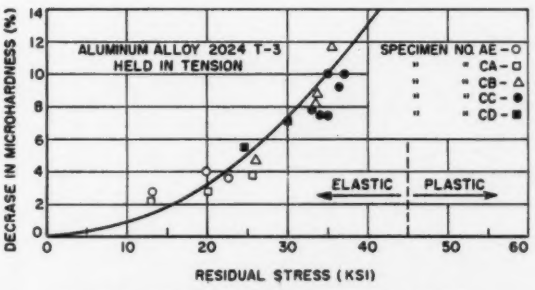

FIG. 1. RESULTS OF TESTS ON THE ALLOYS

problem of relaxation did make it impossible to retain the maximum elastic strain without progressing into the plastic region on initial load. As a consequence, the hardness values at maximum elastic strain have not been determined.

The results of the tests on the alloys studied are shown in Fig. 1, in which the percent of decrease in microhardness is plotted versus residual stress. The most important information provided is that the variation of microhardness with elastic strain is not linear, as has been reported previously.[3,6] A good fit to the data is obtained by assuming that a parabolic relationship exists between the variables. The equation for such a relationship would thus be

$$\textit{Percent of Decrease in Microhardness} = C\,(\textit{Residual Stress})^2.$$

A value of C was obtained statistically as 8.1×10^{-3} for the data presented herein.

Fink and Van Horn[1] found a nonlinear variation of Rockwell B hardness versus elastic stress in aluminum alloy 2017. However, they employed only six experimental points to plot their curves and used simple beam loading rather than uniaxial stressing.

An explanation of the above relationship for the alloy 2024-T3 cannot be provided at this time. Further work is planned on other alloys, and it seems appropriate that a general explanation should not be attempted until similar detailed examinations are made in these systems.

ACKNOWLEDGMENT

The authors gratefully acknowledge the sponsorship of the Transport Division of the Boeing Airplane Company for its support of this program.

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THE ACHIEVEMENT OF EXCELLENCE

(Continued from page 2)

I find little consolation in the prospect of more large lectures. And I remain skeptical about the efficacy of mechanical devices such as the television set, although I must confess that the television lectures I have witnessed have had higher quality than some of the dull teaching I have experienced. The trouble is you can't talk back to a television set, and you can't let down your intellectual hair with it. I suppose you can, but you won't get much of a response. And the young monitors to whom you will be able to talk after the television lecture will have to be exceedingly good if you are to escape the anticlimactic feeling of dealing with a substitute.

If we are to make excellence a goal in the decade ahead, we must try to find ways, however difficult this may be, to preserve the mind-to-mind, spirit-to-spirit relationship of good student to good teacher. Only with such nourishment can excellence grow on any suitable scale. I hold with the view of one of my most respected teachers, one of the great scholars in the history of the University of Oregon, Dean Henry D. Sheldon. Dr. Sheldon once described the growth of a mind toward excellence as consisting of three stages: one of discipleship, one of maturity, and one of mastery. Without discipleship there is certainly less likelihood of maturity and mastery.

Even at best, and with bold, intelligent leadership from our colleges and universities, the reformation of our society into a suitable nurturing ground for excellence will be slow. Happily we are aware of what must be done, and we live in a climate today where the aspiration toward excellence can breathe more freely. Hopefully we shall some day reach the stage at which the man in the street will respect and encourage excellence in all areas as he now does in some. Then the episode which once happened in San Francisco will not be carried in the newspaper as it was the other day, because it will not be news. Some years ago, Alfred Hertz conducted the San Francisco Symphony orchestra in a brilliant performance of Beethoven's Ninth Symphony. Next day, Hertz was lunching with a friend at the famous old Solari's restaurant. Looking out the window the friend saw a policeman placing something on the windshield of his guest's car. He rushed out and said, "Officer, that car belongs to Dr. Hertz. Please don't put a ticket on it." The officer replied, "I'm not putting a ticket on it, sir. I heard the Ninth last night, and I'm just leaving the good Doctor a letter of appreciation."

CANDID CRITICISM

Maybe everyone should add a leather-covered couch to his office equipment? "In the past few years more and more articles dealing with the professional status of the engineer have appeared. Many apparently stem from certain inner conflicts that psychologists might call inferiority complexes. A casual perusal of articles by lawyers and physicians shows no comparable anxiety regarding 'status'. A lawyer does not wonder, aloud, whether his work is professional in nature, nor does a physician question whether his routine as a specialist in a narrow field separates him from his 'profession' and relegates him to the status of a mere 'technician.' Apparently the only educated people who do such soul searching are engineers. Why do they waste time in such unprofitable self-analysis?" E. R. Harrington, "Engineers, Atomic Physics, and Mathematics," *Civil Engineering*, Vol. 30, Feb., 1960, p. 42.

Engineering Research Dividends

Recent theses submitted for advanced degrees from the College of Engineering, University of Washington, will regularly appear in abstract form in *The Trend*. Complete copies of these theses are available for reference at the University of Washington Library. Address inquiries to the Director of the Engineering Experiment Station, University of Washington, Seattle 5.

COLLINGHAM, R. E., "Measurement of Acoustic Velocity in Very Wet Steam," M.S. in Engineering, 1960.

In order to explain the large discrepancies between theory and experimental results in two-phase critical flow rates of steam-water mixtures, this investigation experimentally measured the acoustic velocity in steam-water mixtures. The acoustic velocity was measured at 15 and 45 psia over the range of qualities $x = 26.6\text{-}100\%$. The propagation of this sound or pressure wave was not as predicted by thermodynamic equilibrium methods, but was completely metastable. The acoustic velocity was a constant (i.e., independent of quality) and was dependent upon pressure.

When the flow in a passage no longer increases with a decrease of back pressure, critical flow exists. A prediction of two-phase critical flow rates was made. A comparison of the prediction with experimental results is included. From this comparison, approximate slip values were calculated.

Reynold's critical flow theory was proven for two-phase flow.

IP, H. W., "Turbulent Mixing between Two Parallel Jets along a Flat Plate with Initial Boundary Layers," M.S. in Mechanical Engineering, 1960.

This thesis presents results of an analytical and experimental investigation of the two-dimensional, isothermal, turbulent mixing between two parallel, incompressible streams of air at different velocities, when one stream issues from a narrow slot parallel and adjacent to a flat plate and the other is considered to be a semi-infinite free stream. The effects of the initial boundary layers are taken into account.

In the theoretical solution of the problem, Prandtl's simplification of the Navier-Stokes equation is used. By employing the method of transformation of variables, together with certain assumptions, the apparent kinematic viscosity is transformed out of the equation of motion. The transformed equation, which is written in a finite-difference form, is solved by iteration method with the aid of an IBM-650 computer.

The transverse velocity profiles obtained in the experiment reveal the general trend of the flow pattern in the mixing process. An attempt is made to arrive at a suitable expression for the mixing coefficient by comparing the theoretical and experimental results. Correlation was found to be satisfactory in the mixing region, but discrepancy exists in the wall boundary layer.

KOLESAR, D. C., "An Analysis of the Shield Design for the 10-KW University of Washington Training Reactor," M.S. in Engineering, 1960.

The primary objective of this study was to calculate the radiation dose expected at the surface of the heavy concrete shield of the 10-kw University of Washington Training Reactor. The analysis was conducted by utilizing the IBM-650 digital computer. Machine programs were selected from the numerous programs available that would facilitate the shielding calculations. Consequently, a complete outline of the various programs used—including input preparation, input format, output format, and operating instructions—is included in this thesis.

The radiation escaping the shield region perpendicular to the fuel "slabs" is calculated to be 8.55×10^{-3} mr/hr of gamma rays and 3.6231 mr/hr of neutrons.

LAINE, D. D., "An Extended Time Electromechanical Analog Computer," M.S. in Mechanical Engineering, 1960.

The purpose of this project was to develop a mechanical analog computer capable of solving linear second-order differential equations of the type $A\ddot{X} + B\dot{X} + CX = f(t)$. A World War II Navy-surplus dead-reckoning computer that contained several basic computing elements was used as the framework in developing the computer.

The extended-time electromechanical analog computer that was developed has demonstrated the solutions to certain linear second-order homogeneous

differential equations. The computer contains two integrators and two narrow-band multipliers from the dead-reckoning computer, together with other computing components. This computer is unique because, although it is primarily mechanical, the components may be patchboarded readily through the use of a Selsyn component-interconnection system.

The input and output shafts of each mechanical computing element are fitted with Selsyns. A series of three lead cables is used for mechanizing the equations whose solutions are desired. Negative transfer functions may be inserted merely by reversing two of the cable leads on one of the Selsyns involved. The power required to operate the computer is 110v, ac and dc; the instrumentation power source is a 70-v d-c regulated power supply. Solutions are recorded on a Brush six-channel recorder.

This computer has a demonstrated accuracy of more than 98% over the integration range. Its solution time is long, so as to reduce instability and errors caused by component inertia.

MILLER, R. D., "Low Temperature Vibration Damping Qualities of Metals Determined by Foil Strain Gages," M.S. in Mechanical Engineering, 1960.

The first phase of work described is the determination of the operating characteristics of electric resistance foil strain gages at temperatures ranging from room temperature down to about that of liquid nitrogen (80° to – 300°F). The operating characteristics studied were the changes of the gage factor and the zero drift of the gages with temperature. It was found that the gage factor did change with temperature, decreasing with decreasing temperature, but not in a set manner, as each type of gage behaved differently. The zero drift, with the gages connected so that they were temperature compensated, was somewhat erratic with gages not waterproofed, but was fairly constant and showed very little drift with waterproofed ones. Four types of gages were used: ½-in. paper-backed, ½-in. epoxy-backed, ½-in. bakelite-backed, and ⅛-in. paper-backed foil gages (FAP-50-12, FA-50-12, FAB-50-12, and FAP-12-12).

The second phase of the work was the determination of the overall internal friction of a steel and an aluminum specimen from room temperature to about –250°F. The foil strain gages were used to record the free and forced vibrations of the specimens from which the logarithmic decrement, equivalent viscous damping, and the ratio of the amplitudes of vibration at resonance at any temperature to room temperature was calculated through the above temperature range. The results were plotted on graphs. In both the aluminum and the steel specimens, the internal friction decreased with decreasing temperature to a minimum and then, below this minimum, increased with decreasing temperature.

The natural frequency of vibration, both theoretical and experimental, and the modulus of elasticity for steel and aluminum were also calculated, and the results were plotted through the same temperature range as before.

OKUMURA, H. Y., "A Study of Phase Transformations in Zirconium-Vanadium Eutectoid Alloys," M.S. in Metallurgical Engineering, 1960.

An investigation of high-purity Zr-V alloys ranging in composition from 3 to 6 wt%-V was studied. The solid-state constitution of these alloys was investigated, to determine more accurately the eutectoid composition.

Studies of alloys slow cooled and water quenched from 940 ± 10°C revealed that the eutectoid composition was somewhere between 3 and 4 wt%-V, this being less than the 5% reported by J. T. Williams in 1955. The sharp change in microstructure between 3 and 4%-V slow-cooled alloys and the observation of an isothemal ZrV_2 phase in 4%-V alloys water quenched from 940°C established the eutectoid composition to be less than 4%-V.

Under conditions of water quenching from temperatures around 940 ± 10°C, the beta transformed to alpha prime in 3%-V alloys and was partially retained in 4 to 6%-V alloys. The retained beta was accompanied by omega, which formed during the quench, and isothermal ZrV_2.

The aging of hypereutectoid 4%-V alloy water quenched from 1150°C produced an omega transition phase as the initial product of beta decomposition. An indexing of the X-ray diffraction-line positions of omega showed that the omega phase was tetragonal and had an a_o of 10.77Å and a c/a ratio of 1.018.

The Rising Tide of Publication. Scientific journals received at the Science Museum Library (of Great Britain) are increasing at the rate of almost two per day (700 in a year). This increase is expected to grow to 1000 a year. One reason for the surge is the development of new research institutions in China, Japan, and other countries where scientific work is growing enormously. Another reason is the authors' practice of publishing the same material several times. Scientists are condemning the duplication in publication and the frequently worthless content of the material. *Nature* (London), as cited in *Technical Survey*, Vol. 16, No. 21, May 21, 1960.

Notes and Comments

ENGINEERS IN THE NEWS

G. S. Smith, Professor of Electrical Engineering, retired from the University in June after 39 years of service.

W. G. Bauer, Lecturer in Ceramic Engineering, has developed a machine called the "Thermomill," an invention for flash drying and grinding fibrous materials. Designed as part of his work with a refuse-disposal program for Spokane, the machine offers a means of utilizing garbage and other wastes, which it reduces to a fiber product marketable for compost and other uses. The Thermomill operated successfully in a pilot-plant test that was part of the work at Spokane. It has also been used for flash-drying and fiberizing wood chips. Graduate students in Ceramic Engineering assisted in developing the machine.

On June 10, **F. B. Farquharson,** Director of the Engineering Experiment Station, addressed the tenth annual national convention of the Society of Women Engineers, which was held in Seattle.

A. A. Hemenway, Project Engineer at Boeing Airplane Company and formerly Assistant Professor of Humanistic-Social Studies, is a sponsor of two industry-education programs to improve science and mathematics education. The programs are to offer employment to qualified high-school science and mathematics teachers and to provide summer engineering and science research projects for gifted high-school students.

Beginning in September, **P. C. Paris,** Assistant Professor of Civil Engineering, will be on leave during a period of advanced study at Lehigh University.

Engineering News-Record for June 16 comments favorably in an editorial upon an article by Seattle engineer **H. M. Hadley** on simplifying shear transfer. In the May 26 number of the magazine Hadley reported that shear can be effectively transferred between the flange of a steel beam and a concrete slab in composite construction on bridges and buildings by welding small metal beads onto the steel flange. **H. P. Mittet,** Associate Professor of Civil Engineering, made the exploratory tests showing that the process provides unit shear stresses exceeding 400 psi.

A new University Press book, *Theories of Scientific Method: The Renaissance through the Nineteenth Century,* is a survey of five centuries of Western Scientific thought. The authors are Professors R. M. Blake and C. J. Ducasse of Brown University and E. H. Madden of San Jose State College. Professor Madden edited the book.

MOTOR-TRANSPORT STUDY COMPLETED

A research study of "Motor Transport Fuel Consumption Rate and Travel Time" made under the direction of Roy B. Sawhill, Associate Professor of Civil Engineering, was completed recently; and a report on the subject, coauthored with Joseph C. Firey, Associate Professor of Mechanical Engineering, has been submitted to the Bureau of Public Roads. This study has national interest; it is associated with the Highway Bill of 1956, which requires the measurement of benefits to the various highway users. The work was supported by a grant of $25,000 from the Bureau of Public Roads and one of $32,000 from the Washington State Highway Commission.

This study is considered to be very comprehensive with regard to the number of truck-type vehicles tested and the variety of operational characteristics observed. The data presented in the report will be beneficial to the economical planning and design of highways, as well as to the assignment of cost responsibility. Comparisons and analysis are now possible for fuel and time savings by improving the surfacing of the roadway, removal or reduction of stops, elimination of congestion and slowdowns, reduction of grades, shortening of grades, or control of operating speeds.

A complete report on the research study will be available in the near future as a Highway Research Board Bulletin.

NEW RESEARCH GRANTS

Three new research contracts to be supervised by members of the engineering faculty have recently been awarded to the University.

A grant of $23,000 has been received from the Bureau of Public Roads for a "Continuation of Federal Land Use Study." The work is to continue research work begun a year ago; it concerns the interrelationships between transportation and land use. The research is coordinated by Edward M. Horwood, Associate Professor of Civil Engineering. Among others participating in it are Dr. William L. Garrison, Professor of Geography, Northwestern University, and Dr. Duane F. Marble, Assistant Professor of Regional Science, the University of Pennsylvania. Data being gathered from agencies

throughout the country are expected to result in two volumes of study. During a period of lecture and study in Europe, Professor Horwood expects to gather usable information on European practices in the acquisition of land-development rights near highway interchanges.

Under the sponsorship of the U.S. Atomic Energy Commission, Douglas H. Polonis, Associate Professor of Metallurgical Engineering, is to head an investigation of "Phase Transformations in a Eutectoid Binary Alloy System." The object of this research is to advance basic understanding of the kinetics and mechanisms of these transformations. Initial studies will be made upon the titanium-copper system, the emphasis being given to alloys containing less than 10 atomic per cent of copper. The investigation will include study of the tempering of wartensitically transformed beta phase by means of X-ray diffraction, metallography, and precise electrical-resistivity measurements; of the effects of alloy composition and tempering temperature on the kinetics of tempering; and of the precipitation of Ti_2Cu from supersaturated alpha phase to determine the effects of alpha morphology on the precipitation reaction. The grant is for $11,619.

Under a contract with the Office of Naval Research and under the sponsorship of the Naval Research Laboratory, a grant of $8,000 is to be used for study of "Long Wave Antennas." Donald K. Reynolds, Associate Professor of Electrical Engineering, will supervise this research.

NEW REPRINTS AND NEW REPRINT POLICY

Thirteen new reprints of papers by engineering faculty members are available for distribution through the Engineering Experiment Station. Three others that have not been delivered by the publishers should be added to this list within the next month. Thereafter, no new ones are to be issued, the Experiment Station Board having ruled that none will be purchased except those just mentioned, which were ordered to fulfill promises made to authors. The reprints have become so costly, the Board stated, that the sum earmarked for them could be used more advantageously in other ways. In its memorandum to the faculty, the Board suggests that circumstances could change so as to merit a reversal of the policy announced.

The following new reprints are available:

Reprint No. 161. "Flooding Characteristics and Separation Efficiencies of Pulsed Sieve-Plate Extraction Columns." L. D. Smoot, B. W. Mar, and A. L. Babb, *Ind. Eng. Chem.*, Vol. 51, No. 9, Sept., 1959.

Reprint No. 162. "Longitudinal Mixing in a Pulsed Sieve-Plate Extraction Column." B. W. Mar and A. L. Babb, *Ind. Eng. Chem.*, Vol. 51, No. 9, Sept., 1959.

Reprint No. 163. "Center City Goods Movement: An Aspect of Congestion." E. M. Horwood, *Bulletin 203* (1958). Highway Research Board, Washington, D.C.

Reprint No. 164. "Measurement of Central Business District Change and Urban Highway Impact." E. M. Horwood and R. R. Boyce, *Bulletin 221 (1959)*, Highway Research Board, Washington, D.C.

Reprint No. 165. "An Appraisal of Measures for Improvement of Slope Stability." R. G. Hennes, S. E. Hawkins, and E. L. McCoy, *Bulletin 216, (1959)*, Highway Research Board, Washington, D.C.

Reprint No. 166. "Studies of the Cation Exchange System Fe^{+++}–H^{+}." R. C. Vasishth and M. M. David, *A.I.Ch.E. Journal*, Vol. 5, No. 3, Sept., 1959.

Reprint No. 167. "Planning a Good Professional Meeting." P. L. Balise, *Journal of Engineering Education*, Vol. 50, No. 1, Oct., 1959.

Reprint No. 168. "Reaction Rate Constants by Radioactive Tracer Techniques." D. M. Himmelblau and A. L. Babb, *Ind. Eng. Chem.*, Vol. 51, No. 11, Nov., 1959.

Reprint No. 169. "On the Propagation of Electromagnetic Waves Through Anistropic Layers." G. Tyras and G. Held, *IRE Transactions on Antennas and Propagation*, Vol. AP-7, Special Supp., Dec., 1959.

Reprint No. 170. "Self Diffusion in Liquids. II. Comparison between Mutual and Self-Diffusion Coefficients." A. P. Hardt, D. K. Anderson, R. Rathbun, B. W. Mar, and A. L. Babb, *Jour. Physical Chem.*, 63, 2059 (1959).

Reprint No. 171. "Analysis and Synthesis of Radiation Patterns from Circular Apertures." A. Ishimaru and G. Held, *Can. Jour. Physics*, Vol. 38 (1960).

Reprint No. 172. "A Study of Boundary Conditions in Slip-Flow Aerodynamics," Robert E. Street, *Rarefied Gas Dynamics*, Pergamon Press, 1960.

Reprint No. 173. "Relativity and the Mechanical Engineer." B. D. Mills, Jr., *Mech. Engg.*, April, 1960.

NEW PROJECTS

Project No. 289. Inducing Flow Separation in Over-expanding Bell-shaped Nozzles. Supervisor: M. Guidon III, Associate Professor of Mechanical Engineering; Research Assistant: J. L. McLaughlin.

Project No. 290. An Electromechanical Analog Computer. Supervisor: P. L. Balise, Associate Professor of Mechanical Engineering; Research Assistant: D. D. Laine.

Project No. 291. Effect of Reaction Rates on High-Temperature Characteristics of Refractories, Phase I and Shrinkage of Fireclay Refractories. Supervisor: J. I. Mueller, Professor of Ceramic Engineering; Research Assistant: K. N. Johnson.

Project No. 292. Comparison of Methods of Determining Surface Areas of Finely Divided Powders. Supervisor: R. J. Campbell, Jr., Assistant Professor of Ceramic Engineering; Research Assistant: I. Walton.

Project No. 293. Determination of Solid State Transformations by Electrical Resistivity Methods. Supervisor: C. E. McNeilly, Assistant Professor of Ceramic Engineering; Research Assistant: D. L. Cross.

Project No. 294. Coordination of Instructional Use, Maintenance, and Programming of the IBM-610 Computer. Supervisor: P. L. Balise, Associate Professor of Mechanical Engineering; Research Assistant: M. A. Shirazi.

Project No. 295. Control of Grain Size in Polycrystalline Ceramic Bodies. Supervisor: J. I. Mueller, Professor of Ceramic Engineering; Research Assistant: W. J. Harrison.

Project No. 296. Effects of Acceleration on Peak Heat Flux in Nucleate Boiling. Supervisor: C. P. Costello, Assistant Professor of Mechanical Engineering; Research Assistant: J. M. Adams.

PROFESSORS ABROAD FOR LECTURE AND STUDY

More than the usual number of men associated with the College of Engineering are among the University faculty members traveling outside the United States for educational activity this year. Two of these are to deliver papers; the others are on leave for six months or more.

Frank Neumann, Seismologist in the Department of Geology, will participate in the Second World Conference on Earthquake Engineering, which meets at Tokyo and Kyoto, Japan, on July 11 to 18. Professor Neumann will present a paper, entitled "A Broad Formula for Determining Lateral Force on Oscillators," which offers the first formula of its kind based on seismological concepts rather than trial-and-error methods. On his return journey, he will spend some time in Europe, to complete an around-the-world jaunt.

Charles P. Costello, Assistant Professor of Mechanical Engineering, and W. E. Tuthill, M.S. graduate in engineering, 1959, are coauthors of a paper presented at the joint meeting of AIChE with IMIQ (Chemical Engineers of Mexico) on June 19-22 in Mexico City. Professor Costello read the paper, entitled "Effects of Acceleration on Nucleate Pool Boiling."

Edgar M. Horwood, Associate Professor of Civil Engineering, was awarded a Fulbright grant, under which he will give lectures and do research in Europe next fall. He will lecture on urban planning and transportation planning at the Technical Institute of Denmark in Copenhagen. He will also lecture at other universities; study mass rapid transit in Scandinavia; and attend international conferences in Sweden and France. He is to leave Seattle July 29, and plans to return in January.

The April *Trend* reported that Robert G. Hennes, Professor of Civil Engineering, was to set up a graduate program in soil mechanics at the Bengal College of Engineering in Calcutta, India. Professor Hennes, who is now in India, plans to tour Europe with his family on their way home next spring. As the January *Trend* reported, Eugene P. Richey, Associate Professor of Civil Engineering, was awarded a National Science Faculty fellowship for next year. He will begin his leave in August; he is to study hydraulic engineering at the Technological University, Delft, the Nederlands.

SCHIZOPHRENIA IN ENGINEERING

(Continued from page 1)

Medicine has long had its own doctor of medicine degree, which academicians rank below the doctor of philosophy degree. On engineering faculties, possession of the Ph.D. degree sometimes engenders a reluctance to introduce doctorates of "lower rank." Although such distinctions may seem preposterous to practicing engineers, the effect on the future of the profession can be serious.

The situation in engineering today is not unlike that which would exist in medicine if research medical doctors suddenly began to feel that research was the only important aspect of their profession, and if the practicing medical physician was suddenly downgraded to a second-class status.

Even worse, the qualifications for engineering are in grave danger of being regarded as secondary to those for science, if indeed this has not already happened.

In high-school counseling, where the future of engineer-

ing really lies, the brightest students are being urged to go into science. Such misinformed counseling can be the death-knell of engineering, and in the future can greatly weaken the Nation. Counselors have often had some training in science but seldom in engineering; they may be unduly influenced by the scientific aspects of Sputniks, forgetting the engineering aspects.

For a strong Nation we must have strong and coordinate science and engineering. The interest of students in particular types of activity must be determining, not relative intellect. To do otherwise is to say that all bright students should be scientists regardless of personal interest.

What should the engineering profession do about these problems? First, it should increasingly apply its own methods of engineering analysis to a greater extent at both bottom and top professional society levels to determine clearly what its future should be. Steps taken so far have been inadequate. Imagine the legal profession allowing either scientists or labor unions to determine its future by default. Second, it should take additional organized steps to see that its objectives are realized. Third, the engineering teaching profession through the American Society for Engineering Education should assist vigorously in the overall effort by implementing a strong grass-roots organization. The problem is too complex for a small group of men at the top alone. It should then try to eliminate the confusion in its own thinking.

A first step might also be to counter the public statements of certain persons that engineering is still plodding along with the methods of thirty years ago. Such statements may be made by the uninformed, or for internal consumption to prod and stir discussion. In either event, released to the general public, they do great harm to engineering; and they are not true. Good engineering schools attempt to evolve with the times in accordance with their own ideas as to how they may best serve the profession and the Nation, realizing that the pattern of engineering education today determines the engineer of tomorrow. Clarification of objectives by the profession itself would help the process materially.

OUTSIDE U.S.A.

Highlights from Our Foreign-Exchange Publications

AN ECONOMICAL ALUMINUM CROSS SECTION. Carl-Adolph Granholm, *Chalmers Tekniska Högskolas Handlingar,* No. 220, 1959. Swedish; English summary.

This paper presents a standard series of aluminum I-sections. The sections were designed with regard for the modulus of elasticity and the high price of aluminum, which imply slenderer webs and flanges and better use of the material than in comparable rolled-steel I-beams. Owing to the economical design and the low density of aluminum, the weight of such beams is about 20 to 25% that of rolled steel beams with the same bearing capacity.

An extensive experimental investigation was made to verify practically the calculated risk of local buckling of webs and flanges under different conditions of loading. The tests showed that the risk of web buckling through moments and shear forces does not limit the permissible stresses, although the thickness of the web is only 1/80th the height of the section. The total width of the flanges is about 20 times their thickness. The tests also showed that local buckling does not limit the working stresses. Tests on very short beams show that the capacity of the short beam to resist large concentrated loads is excellent and that beam stiffeners are usually unnecessary. If stiffeners are required for concentrated loads, a simple type somewhat longer than the free distance between flanges is suggested. This kind need not be welded nor bolted: pressing between the flanges was found to be sufficient. This very simple, inexpensive stiffener increases the capacity of the beam to resist concentrated loads by about 50%.

These beams are likely to buckle laterally; thus they must be stiffened laterally. A full-size test with a roof of corrugated aluminum sheet mounted on purlins having the I-shaped section showed that the sheet metal can provide the needed stiffening. This kind of beam has also been used for purlins in some roof constructions consisting of corrugated aluminum sheets provided with exterior heat insulation.

The tests and experience gained from the construction showed that these lightweight beams can compete with rolled steel beams, even without taking into account the advantages of reduced weight and of eliminating maintenance costs.

INFLUENCE OF FREQUENCY OF STRESS CYCLES ON FATIGUE AT ELEVATED TEMPERATURES. Shuji Taira and Ryoichi Koterazawa, *Bulletin of JSME,* Japan Society of Mechanical Engineers, Vol. 3, No. 10, 1960. English.

Rotating bending fatigue tests under constant strain amplitude were carried out with a 0.55% carbon steel and a 13 chromium steel to study the influence of frequency of stress repetition on the fatigue strength of materials. The test temperature was from 450° C to 600° C; the frequencies of stress cycles were 170 and 1500 cpm. Both the 0.55% carbon steel and the 13 chromium steel showed the fatigue behavior characteristic of elevation above a critical temperature: at high amplitude, the specimens fractured at a definite number of stress cycles, irrespective of frequency; at lesser amplitude, specimens tested at lower frequency fractured at fewer cycles than those at higher frequency. These characteristics, which are the same as those of low-carbon steel studied previously, suggest that the fatigue at elevated temperatures is a sort of rate process closely related to the plastic deformation of material under alternating load.

RANDOM SIGNALS IN ENGINEERING SYSTEMS. J. H. Milsum, *Quarterly Bulletin of the Division of Mechanical Engineering and the National Aeronautical Establishment,* National Research Council of Canada, No. DME/NAE, 1960.

This article reviews the description of random signals in a variety of circumstances, gives examples of them, and discusses analytical and computational techniques for handling systems subjected to the signals. The discussion relates the signals to hardware systems, natural systems, and living organisms.

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